United States Environmental Protection Agency
Office of Water
4503 F
Washington DC 20460
EPA 841-B-99-004
October 1999

Protocol for Developing Sediment TMDLs

First Edition

Acknowledgments

The *Protocol for Developing Sediment TMDLs* was prepared under the direction of Donald Brady and Chris Zabawa of EPA's Office of Wetlands, Oceans, and Watersheds, Assessment and Watershed Protection Division, and Mimi Dannel, Office of Science and Technology, Standards and Applied Science Division. The document was developed under EPA Contract 68-C7-0018. Th *Protocol for Developing Sediment TMDLs* was written by EPA's Sediment Protocol TMDL Team, led by David W. Smith of EPA Region 9, with assistance from John Craig of Tetra Tech, Inc., in Fairfax, Virginia. The authors gratefully acknowledge the many comments of reviewers from within EPA and stat environmental agencies, as well as the detailed reviews conducted by Lee MacDonald of Colorado State University and Thomas Lisle of USDA Forest Service, Redwood Sciences Laboratory.

This report should be cited as:

U.S. Environmental Protection Agency. 1999. Protocol for Developing Sediment TMDLs. EPA 841-B-99-004. Office of Water (4503F), United States Environmental Protection Agency, Washington D.C. 132 pp.

To obtain a copy of the *Protocol for Developing Sediment TMDLs/EPA 841-B-99-004 (1999)* free of charge, contact:

National Service Center for Environmental Publications (NSCEP)
Phone: 513-489-8190
Fax: 513-489-8695

This EPA report is available on the Internet at:

http://www.epa.gov/owow/tmdl/techsupp.html

Protocol for Developing Sediment TMDLs

First Edition: October 1999

Watershed Branch
Assessment and Watershed Protection Division
Office of Wetlands, Oceans, and Watersheds
Office of Water
United States Environmental Protection Agency
Washington, DC 20460

Foreword

Although many pollution sources have implemented the required levels of pollution control technology, there are still waters in the nation that do not meet the Clean Water Act goal of "fishable, swimmable." Section 303(d) of the act addresses these waters that are not "fishable, swimmable" by requiring states, territories, and authorized tribes to identify and list impaired waters every two years and to develop total maximum daily loads (TMDLs) for pollutants in these waters, with oversight from the U.S. Environmental Protection Agency. TMDLs establish the allowable pollutant loadings, thereby providing the basis for states to establish water quality-based controls.

Historically, wasteload allocations have been developed for particular point sources discharging to a particular waterbody to set effluent limitations in the point source's National Pollutant Discharge Elimination System (NPDES) discharge permit. This approach has produced significant improvements in water quality by establishing point sourc controls for many chemical pollutants. But water quality impairments continue to exist in the nation's waters. Some point sources need more controls, and many nonpoint source impacts (from agriculture, forestry, development activities, urban runoff, and so forth) are causing or contributing to impairments in water quality. To address the combined, cumulative impacts of both point and nonpoint sources, EPA has adopted a watershed approach, of which TMDLs ar a part. This approach provides a means to integrate governmental programs and improve decision making by both government and private parties. It enables a broad view of water resources that reflects the interrelationship of surfac water, groundwater, chemical pollutants and nonchemical stressors, water quantity, and land management.

The *Protocol for Developing Sediment TMDLs* is a technical guidance document prepared to help state, interstate, territorial, tribal, local, and federal agency staff involved in TMDL development, as well as watershed stakeholders and private consultants. Comments and suggestions from readers are encouraged and will be used to help improve th available guidance as EPA continues to build experience and understanding of TMDLs and watershed management.

Robert H. Wayland III, Director
Office of Wetlands, Oceans, and Watersheds
Office of Water
US Environmental Protection Agency
Washington, DC 20460

Preface

EPA has developed several protocols as programmatic and technical support guidance documents for those involved in TMDL development. These guidance documents have been developed by an interdisciplinary team and provide an overall framework for completing the technical and programmatic steps in the TMDL development process. Th *Protocol for Developing Sediment TMDLs* is one of the three TMDL technical guidance documents prepared to date. The process presented here will assist with the development of rational, science-based assessments and decisions and ideally will lead to the assemblage of an understandable and justifiable sediment TMDL. It is important to note that this guidance document presents a suggested approach, but not the only approach to TMDL development.

This document provides guidance to states, territories, and authorized tribes exercising their responsibility under section 303(d) of the Clean Water Act for the development of sediment TMDLs. The protocol is designed as programmatic and technical support guidance to those involved in TMDL development. The protocol does not, however, substitut for section 303(d) of the Clean Water Act or EPA's regulations; nor is it a regulation itself. It cannot impose legally binding requirements on EPA, states, territories, authorized tribes, or the regulated community, and it might not apply to a particular situation based on the circumstances. EPA and state, territorial, and tribal decision makers retain th discretion to adopt approaches on a case-by-case basis that differ from this protocol where appropriate. EPA may change this protocol in the future.

Contents

Figures

Tables

Introduction and Purpose of This Protocol

Objective: This Total Maximum Daily Load (TMDL) protocol was developed to provide EPA regions, states, territories, and tribes with an organizational framework for establishing TMDLs for sediment. The recommendations and methods proposed in this protocol focus on *sediment* as the pollutant; this protocol does not address other contaminants that can be associated with sediment. The process presented here will assist with development of rational, science-based assessments and decisions and ideally will lead to the establishment of an understandable and justifiable TMDL.

Audience: The protocols are designed as tools for state and tribal TMDL staff, EPA regional TMDL staff, watershed stakeholders, and other agencies and private consultants involved in TMDL development.

OVERVIEW

Section 303(d) of the Clean Water Act provides that states, territories, and authorized tribes are to list waters for which technology-based limits alone do not ensure attainment of water quality standards. Beginning in 1992, states, territories and authorized tribes were to submit their lists to the EPA every two years. Beginning in 1994, lists were due to EPA on April 1 of each even numbered year. States, territories, and authorized tribes are to set priority rankings for the listed waters, taking into account the severity of the pollution and the intended uses of the waters.

EPA's regulations for implementing section 303(d) are codified in the Water Quality Planning and Management Regulations at 40 CFR Part 130, specifically at sections130.2, 130.7, and 130.10. The regulations define terms used in section 303(d) and otherwise interpret and expand upon the statutory requirements. The purpose of the *Protocol for Developing Sediment TMDLs* is to provide more detailed guidance on the TMDL development process for waterbodies impaired due to sediments.

On August 23, 1999, EPA published proposed changes to the current TMDL rules at 40 CFR 130.2, 130.7, and 130.10. These changes would significantly strengthen the Nation's ability to achieve clean water goals by ensuring that the public has more and better information about the health of their watersheds, States have clearer direction and greater consistency as they identify impaired waters and set priorities, and new tools are used to make sure that TMDL implementation occurs. The text box on page 1-2 summarizes these proposed changes.

EPA's regional offices are responsible for approving or disapproving state, territorial, or tribal section 303(d) lists and TMDLs, and for establishing lists and TMDLs in cases of disapproval. Public participation is to be provided for by states and tribes (or EPA regional offices, in the case of disapproval) when they establish lists or TMDLs.

In accordance with the priority ranking, states, territories, and authorized tribes are to establish TMDLs that will meet water quality standards for each listed water, considering seasonal variations and a margin of safety that accounts for uncertainty. States, territories, and authorized tribes are to submit their lists and

A TMDL is the sum of the individual wasteload allocations for point sources and load allocations for nonpoint sources and natural background (40 CFR 130.2) with a margin of safety (CWA Section 303(d)(1)(c)). The TMDL can be generically described by the following equation:

$$\text{TMDL} = \text{LC} = \sum \text{WLA} + \sum \text{LA} + \text{MOS}$$

where:
- LC = loading capacity,[a] or the greatest loading a waterbody can receive without violating water quality standards;
- WLA = wasteload allocation, or the portion of the TMDL allocated to existing or future point sources;
- LA = load allocation, or the portion of the TMDL allocated to existing or future nonpoint sources and natural background; and
- MOS = margin of safety, or an accounting of uncertainty about the relationship between pollutant loads and receiving water quality. The margin of safety can be provided implicitly through analytical assumptions or explicitly by reserving a portion of loading capacity.

[a]TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures.

Summary of Proposed Regulatory Requirements for Establishing TMDLs

A TMDL must be established for all waterbody and pollutant combinations on Part 1 of the list. TMDLs are not required for waterbodies on Part 2, 3, or 4 of the list (§ 130.31(a)).

A TMDL must be established according to the priority rankings and schedules (§ 130.31(b)).

TMDLs must be established at a level necessary to attain and maintain water quality standards, as defined by 40 CFR 131.3(l), considering reasonably foreseeable increases in pollutant loads (§ 130.33(b)(9)).

TMDLs must include the following minimum elements (§ 130.33(b)):

1. The name and geographic location, as required by §130.27(c), of the impaired or threatened waterbody for which the TMDL is being established and the names and geographic locations of the waterbodies upstream of the impaired waterbody that contribute significant amounts of the pollutant for which the TMDL is being established;
2. Identification of the pollutant for which the TMDL is being established and quantification of the pollutant load that may be present in the waterbody and still ensure attainment and maintenance of water quality standards;
3. Identification of the amount or degree by which the current pollutant load in the waterbody deviates from the pollutant load needed to attain or maintain water quality standards;
4. Identification of the source categories, source subcategories, or individual sources of the pollutant for which the wasteload allocations and load allocations are being established consistent with §130.2(f) and §130.2(g);
5. Wasteload allocations to each industrial and municipal point source permitted under §402 of the Clean Water Act discharging the pollutant for which the TMDL is being established ; wasteload allocations for storm water, combined sewer overflows, abandoned mines, combined animal feeding operations, or any other discharges subject to a general permit may be allocated to categories of sources, subcategories of sources or individual sources; pollutant loads that do not need to be allocated to attain or maintain water quality standards may be included within a category of sources, subcategory of sources or considered as part of background loads; and supporting technical analyses demonstrating that wasteload allocations when implemented, will attain and maintain water quality standards;
6. Load allocations, ranging from reasonable accurate estimates to gross allotments, to nonpoint sources of a pollutant, including atmospheric deposition or natural background sources; if possible, a separate load allocation must be allocated to each source of natural background or atmospheric deposition; load allocations may be allocated to categories of sources, subcategories of sources or individual sources; pollutant loads that do not need to be allocated may be included within a category of sources, subcategory of sources or considered as part of background loads; and supporting technical analyses demonstrating that load allocations, when implemented, will attain and maintain water quality standards;
7. A margin of safety expressed as unallocated assimilative capacity or conservative analytical assumptions used in establishing the TMDL; e.g., derivation of numeric targets, modeling assumptions, or effectiveness of proposed management actions which ensures attainment and maintenance of water quality standards for the allocated pollutant;
8. Consideration of seasonal variation such that water quality standards for the allocated pollutant will be met during all seasons of the year;
9. An allowance for future growth which accounts for reasonably foreseeable increases in pollutant loads; and
10. An implementation plan

As appropriate to the characteristics of the waterbody and pollutant, the maximum allowable pollutant load may be expressed as daily, monthly, seasonal or annual averages in one or more of the following ways (40 CFR 130.34(b)):
- The pollutant load that can be present in the waterbody and ensure that it attains and maintains water quality standards;
- The reduction from current pollutant loads required to attain and maintain water quality standards;
- The pollutant load or reduction of pollutant load required to attain and maintain riparian, biological, channel or geomorphological measures so that water quality standards are attained and maintained; or
- The pollutant load or reduction of pollutant load that results from modifying a characteristic of the waterbody, e.g., riparian, biological, channel, geomorphological, or chemical characteristics, so that water quality standards are attained and maintained.

The TMDL implementation plan must include the following (§ 130.33(b)(10)):

- A description of the control actions and/or management measures which will be implemented to achieve the wasteload allocations and load allocations, and a demonstration that the control actions and/or management measures are expected to achieve the required pollutant loads;
- A time line, including interim milestones, for implementing the control actions and/or management measures, including when source-specific activities will be undertaken for categories and subcategories of individual sources and a schedule for revising NPDES permits;
- A discussion of your reasonable assurances, as defined at 40 CFR §130.2(p), that wasteload allocations and load allocations will be implemented;
- A description of the legal under which the control actions will be carried out;
- An estimate of the time required to attain and maintain water quality standards and discussion of the basis for that estimate;
- A monitoring and/or modeling plan designed to determine the effectiveness of the control actions and/or management measures and whether allocations are being met;
- A description of measurable, incremental milestones for the pollutant for which the TMDL is being established for determining whether the control actions and/or management measures are being implemented and whether water quality standards are being attained; and
- A description of your process for revising TMDLs if the milestones are not being met and projected progress toward attaining water quality standards is not demonstrated.

TMDLs to EPA for approval and, once EPA approves them, are to incorporate these items into their continuing planning processes. If EPA disapproves a state, territorial, or tribal list and/or TMDL, EPA must (within 30 days of disapproval and allowing for public comment) establish the list and/or TMDL. The state, territory, or tribe is then to incorporate EPA's action into its continuing planning process.

A TMDL is a tool for implementing state water quality standards. It is based on the relationship between sources of pollutants and in-stream water quality conditions. The TMDL establishes the allowable loadings for specific pollutants that a waterbody can receive without violating water quality standards, thereby providing the basis for states to establish water quality-based pollution controls.

For many chemical pollutants, guidance on developing TMDLs is readily available. For some pollutants, however, the development of TMDLs is complicated because of the lack of adequate or proven tools or information on the fate, transport, or impact of each pollutant within the natural system. EPA is developing TMDL protocols to provide guidance on TMDL development. The protocols represent a suggested approach, but not the only approach to TMDL development. EPA will continue to review all TMDLs submitted by states pursuant to Section 303(d) of the Clean Water Act and Title 40 of the CFR, section 130.7.

The TMDL protocols focus on Step 3 (Development of TMDLs) of the water quality-based approach, depicted in Figure 1-1 (USEPA, 1991a, 1999). This specific step is divided into seven components common to all TMDLs, and each component is designed to yield a product that is an element of a TMDL analytical document.

COMPONENTS OF TMDL DEVELOPMENT

The following components of TMDL development may be completed concurrently or iteratively depending on the site-specific situation (Figure 1-2).

- Problem Identification
- Identification of Water Quality Indicators and Target Values
- Source Assessment
- Linkage Between Water Quality Targets and Sources
- Allocations
- Follow-up Monitoring and Evaluation Plan
- Assembling the TMDL

Note that these components are not necessarily sequential steps, but are provided more as a guide and framework for TMDL development. Although some of the submittal components (e.g., TMDL calculation and allocations) are part of the legally required TMDL submittal and others are part of the administrative record supporting the TMDL and providing the basis for TMDL review and approval, this protocol considers each component equally.

Problem Identification

The objective of problem identification is to identify for a listed waterbody the key factors and background information that describe the nature of the impairment and the setting for the TMDL. Problem identification is used to develop a plan for the remaining elements of the TMDL process.

Identification of Water Quality Indicators and Target Values

The purpose of this component is to identify numeric or measurable indicators and pollutant values that can be used to evaluate attainment of water quality standards in the listed waterbody. Often the numeric target value for the TMDL pollutant will be the numeric water quality standard for the pollutant of concern. In some cases, however, TMDLs must be developed for pollutants that do not have numeric water quality standards. When numeric water quality criteria do not exist, impairment is determined on the basis of narrative water quality criteria or identifiable degradation of designated or existing uses (e.g., impaired fishery). The narrative standard is then interpreted and used to develop indicator(s) with quantifiable target(s) to measure attainment or maintenance of the water quality standards.

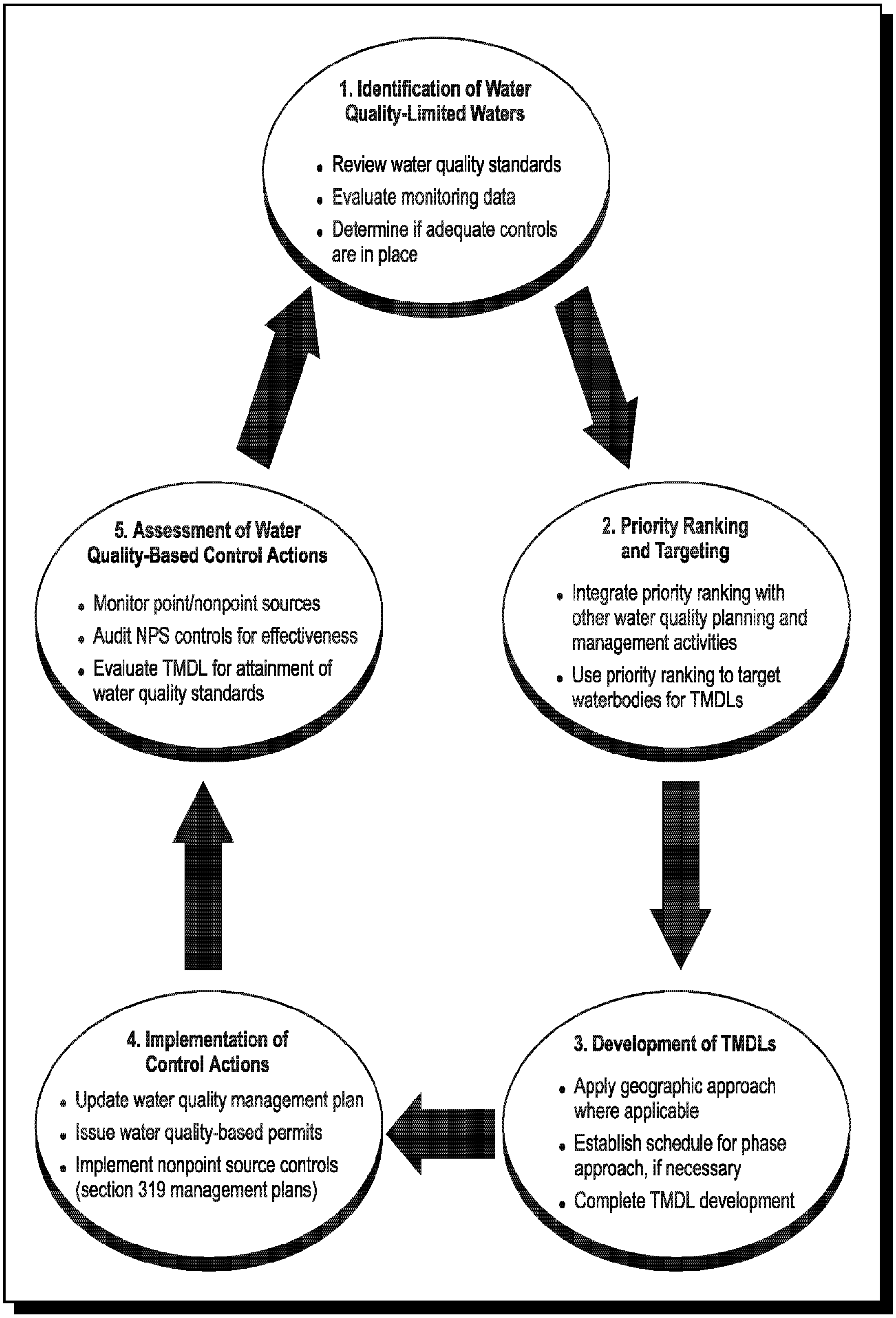


Figure 1-1. General elements of the water quality-based approach (adapted from USEPA, 1991a)

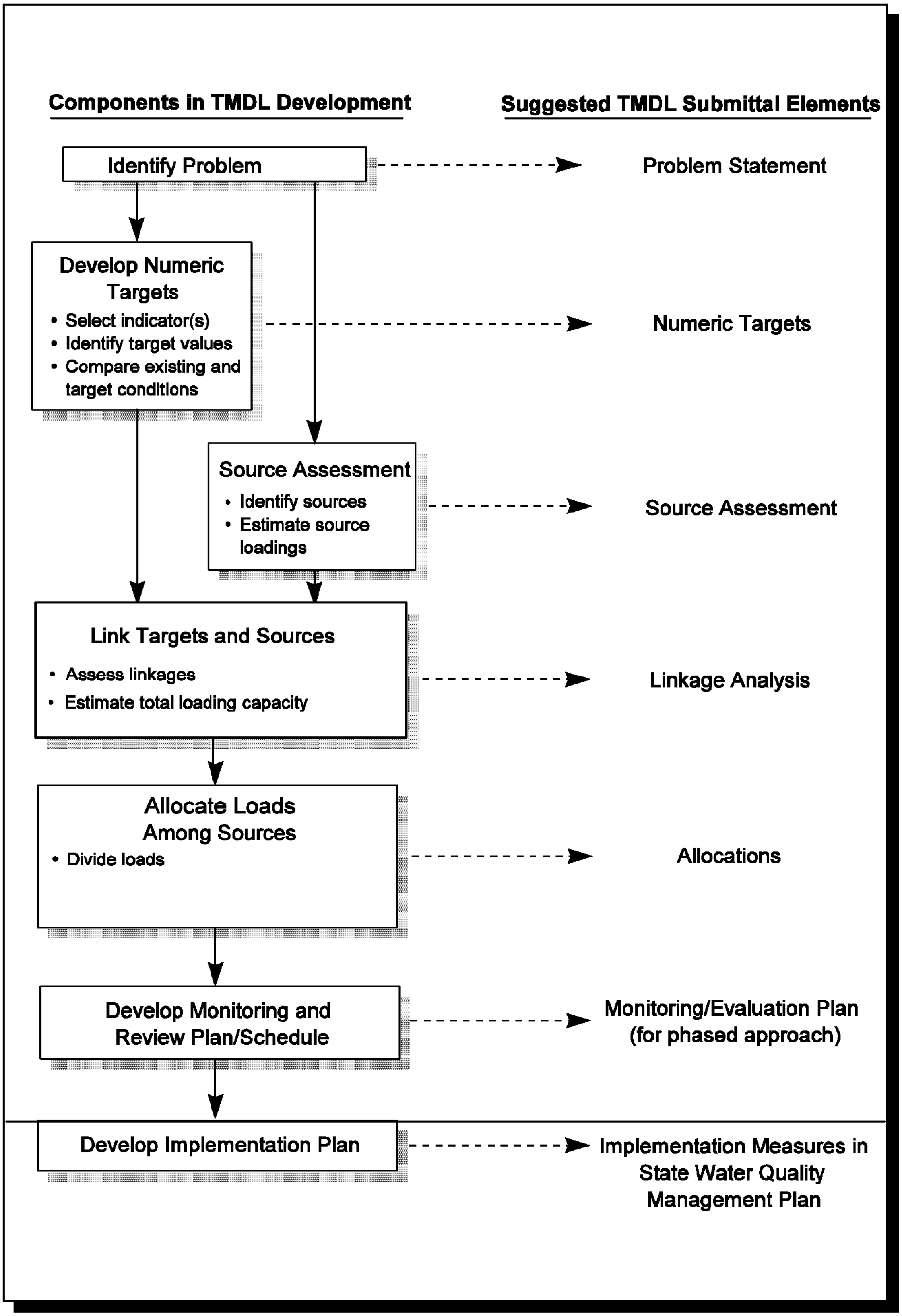


Figure 1-2. General components of TMDL development

Source Assessment

During source assessment, the sources of loading for the pollutant of concern for the waterbody are identified and characterized by type, magnitude, and location.

Linkage Between Water Quality Targets and Sources

For each TMDL, a linkage between the selected indicator(s) and target(s) and the identified sources must be defined. This linkage establishes the cause-and-effect relationship between the pollutant sources and the in-stream pollutant response and allows for an estimation of the loading capacity. The loading capacity is the maximum amount of pollutant loading (e.g., sediment) a waterbody can assimilate without violating water quality standards. Seasonal variation in water quality must be addressed when discussing the linkages.

Allocations

Based on the target/source linkage, pollutant loadings that will not exceed the loading capacity can be determined. These pollutant loadings are distributed or "allocated" among the significant sources of the pollutant. The allocations include wasteload allocations for existing and future point sources and load allocations for natural background and existing and future nonpoint sources. A margin of safety must be included in the allocations to account for uncertainty in the analysis. The margin of safety may be provided implicitly through the use of conservative assumptions in the TMDL development process or explicitly by setting aside a portion of the allowable loading.

Follow-up Monitoring and Evaluation

TMDL submittals often include a monitoring plan to determine whether the TMDL has resulted in attainment of water quality standards and to support any revisions to the TMDL that might be required. Follow-up monitoring is recommended for all TMDLs given the uncertainties inherent in TMDL development (USEPA, 1991a, 1997a, 1999). Although the rigor of a monitoring plan can be based on the confidence in the TMDL analysis, a more rigorous monitoring plan should be considered for TMDLs with high degree of uncertainty and where the environmental and economic consequences of the TMDL are great.

Assembling the TMDL

In this component, the elements of a TMDL submittal package required by statute or regulation are clearly identified and compiled. Supplemental information is also provided to facilitate TMDL review.

For each component addressed in this protocol, the following presentation format is used:

- Guidance on key questions or factors to consider.
- Brief discussions of analytical methods.
- Discussions of products to express the results of the analysis.
- Examples of approaches.
- References on methods and additional guidance.

By addressing each of the TMDL components, analysts can complete the technical aspects of TMDL development. Although public participation is an extremely important component of TMDL development, it is largely outside the scope of this document. The protocols also do not discuss issues associated with TMDL implementation (note the line across Figure 1-1). Methods of implementation such as National Pollutant Discharge Elimination System (NPDES) permits, state nonpoint source (NPS) management programs, and public participation are discussed in Guidance for Water Quality-based Decisions: The TMDL Process (USEPA, 1991a, 1999) and in the August 8, 1997, memorandum "New Policies for Establishing and Implementing Total Maximum Daily Loads (TMDLs)" (USEPA, 1997a).

RECOMMENDED READING

(Note that the full list of references for this chapter is included at the end of the document.)

USEPA. 1991a. Guidance for water quality-based decisions: The TMDL process. EPA 440/4-91-001. U.S. Environmental Protection Agency, Washington, DC. <http://www.epa.gov/owow/tmdl/policy.html>

USEPA. 1995a. Watershed protection: A statewide approach. EPA 841-R-95-001. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1995b. Watershed protection: A project focus. EPA 841-R-95-003. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1997a. New policies for establishing and implementing Total Maximum Daily Loads (TMDLs). U.S. Environmental Protection Agency, Washington, DC. <http://www.epa.gov/owow/tmdl/policy.html>

USEPA 1999. *Draft guidance for water quality-based decisions: The TMDL process (second edition)*. EPA 841-D-99-001. U.S. Environmental Protection Agency, Washington, DC.
<http://www.epa.gov/owow/tmdl/proprule.html>

General Principles of Sediment Water Quality Analysis

Objective: To develop a sediment TMDL, it is important to have a basic understanding of sediment processes in a watershed and how excessive or insufficient sediment can affect water quality and designated uses of water. This section provides background information on sediment impacts on designated uses, sediment sources and transport, and potential control strategies. Naiman and Bilby (1998) and Waters (1995) offer general information discussing sediment water quality.

IMPACTS OF SEDIMENTS ON DESIGNATED USES

Unlike many chemical pollutants, sediment is a vital natural component of waterbodies and the uses they support. However, sediments can impair designated uses in many ways, including those discussed here.

Aquatic life and fisheries

Excessive sediments deposited on stream and lake bottoms can choke spawning gravels (reducing survival and growth rates), impair fish food sources, fill in rearing pools (reducing cover from prey and thermal refugia), and reduce habitat complexity in stream channels. Excessive suspended sediments can make it more difficult for fish to find prey and at high levels can cause direct physical harm, such as clogged gills. In some waters, hydrologic modifications (e.g., dams) can cause sediment deficits that result in stream channel scour and destruction of habitat structure. For more information, see Waters (1995).

Drinking water supply

Sediments can cause taste and odor problems, block water supply intakes, foul treatment systems, and fill reservoirs. Although most treatment systems can remove most turbidity, very high sediment levels sometimes require that water supply intakes be shut down until turbidity clears or system maintenance (e.g., backflushing) is performed.

Recreational use

High levels of sediment can impair swimming and boating by altering channel form, creating hazards due to reductions in water clarity, and adversely affecting aesthetics. Aquatic habitat impairment by sediments can also interfere with fishing.

SEDIMENT SOURCES AND TRANSPORT

Sediment is created by the weathering of host rock and delivered to stream channels through various erosional processes, including sheetwash, gully and rill erosion, wind, landslides, dry ravel, and human excavation. In addition, sediments are often produced as a result of stream channel and bank erosion and channel disturbance. Movement of eroded sediments downslope from their points of origin into stream channels and through stream systems is influenced by multiple interacting factors. Eroded sediments are often trapped on hillslopes and stored in and alongside stream channels. Sediment analyses conducted for TMDLs often account for the influence of these sediment storage and transport mechanisms on the magnitude, timing, and location of sediment-related impairment of designated uses. For more information on sediment sources and transport processes, see Reid and Dunne (1996).

In some settings, land management changes cause changes in runoff even if they do not result in increased upslope erosion. Where this occurs, channel erosion or sediment deposition may increase. It might be appropriate to develop sediment TMDLs to address this type of situation.

Because erosion is a natural process and some sedimentation is needed to maintain healthy stream systems, it is often necessary to evaluate the degree to which sediment discharge in a particular watershed exceeds natural rates or patterns. This analysis can be complicated because sedimentation processes in many systems are highly variable from year to year. This type of analysis is particularly important in settings that are vulnerable to high natural sediment production rates and are particularly sensitive to land disturbance (e.g., the Pacific Northwest and many areas of the desert Southwest). Erosion rates under natural and disturbed conditions can be compared through several approaches, including comparative analysis with reference streams and literature values for similar settings.

SEDIMENT SOURCE CONTROLS

Several approaches are available to manage sediment-related problems, but preventing erosion in the first place is usually the most cost-effective. A variety of management practices have been applied effectively to prevent or reduce erosion from the source. Extensive guidance on sediment best management practices (BMPs) is available from the Natural Resources Conservation Service (NRCS), USDA Forest Service (USFS), and the Bureau of Land Management (BLM), transportation departments, conservation districts, and many state water quality and forest management agencies. In some cases, it is possible to reduce or prevent delivery of eroded sediments to streams by developing or maintaining buffer strips, vegetated swales, or sediment detention basins, some of which also provide collateral benefits in the form of wildlife habitat, nutrient trapping, and stream shading. Sometimes sediment impacts can be managed at relatively high cost after sediments reach waterbodies of concern. Control options include channel and bank restoration and dredging to remove sediments from some types of waterbodies, although dredging can sometimes cause more harm than benefit.

ISSUES IN SEDIMENT WATER QUALITY ANALYSIS

Sediment water quality analysis is less straightforward than analysis of many other pollutants because clean sediment is rarely discharged intentionally to waterbodies. (Dredge and fill operations are an exception.) Rather, adverse sediment discharges usually occur as a result of changes in processes that influence erosion and the capacity of watersheds to store sediment and transport it through the system.

To evaluate potential impacts of land management activities on designated uses, the analyses must assess the influence of land management activities on factors such as changes in erosion processes, water discharge amounts and timing, and channel form. This assessment requires evaluation of the extent to which existing conditions diverge from natural conditions and how existing conditions will respond to planned land management activities. Ideally, the analysis will reconstruct past conditions, accurately describe present conditions, and identify desired future conditions. The condition of the water resource as it relates to erosional processes must be evaluated, and the relationship between erosion processes and impacts must be understood (Figure 2-1).

Key Question	TMDL Element(s)
How do land management activities affect sediment production?	Source Assessment/Allocation
⇓	
How is the sediment routed into the stream?	Source Assessment
⇓	
How is an increased sediment load routed through the stream system?	Source Assessment/Linkage
⇓	
How does the change in sediment affect channel structure and stability?	Targets/Linkage
⇓	
How do changes in sediment loading and channel morphology affect designated uses of concern?	Targets

Figure 2-1. Sediment TMDL logical sequence

The general goal of sediment TMDL analyses is to protect designated uses by characterizing existing and desired watershed condition, evaluating the degree of impairment to the existing (and future) conditions, and identifying land management and restoration actions needed to attain desired conditions.

Although this guidance focuses on sediment as the water quality stressor of concern, analysts should consider the combined effects of multiple pollutants on the designated uses of water resources. For example, streams impaired by the effects of high temperature are typically impaired only during low flow. Assessments that consider multiple pollutants might need to incorporate more analytical work than that necessary to complete a sediment TMDL, but the additional effort would result in development of TMDLs for multiple pollutants.

SEDIMENT TMDLS

TMDL development is pollutant- and site-specific. This protocol provides descriptions of the main elements of TMDLs established for sediments. It also includes case studies from past and ongoing TMDL efforts, as well as hypothetical examples, to illustrate the major points in the process. The protocol emphasizes the use of rational, science-based methods and tools for TMDL development. The availability of data influences the types of methods analysts can use. Ideally, extensive monitoring data are available to establish baseline water quality conditions, pollutant source loadings, and waterbody system dynamics. If long-term monitoring data are lacking, however, the analyst will have to use a combination of monitoring, analytical tools (including models), and qualitative assessments to collect information, assess system processes and responses, and make decisions. Although some aspects of TMDLs must be quantified (e.g., numeric targets, loading capacity, and allocations), qualitative assessments are acceptable as long as they are supported by sound scientific justification or result from rigorous modeling techniques. A goal of this document is to assist analysts in using a rational TMDL development process that incorporates the required elements of a TMDL.

References and recommended reading lists are provided for readers interested in obtaining more detailed background information. The protocols are written with the assumption that analysts have a general background in the technical aspects of water quality management and are familiar with the statutory and regulatory basis for the TMDL program.

Range of Viable Sediment TMDL Approaches

Analysts should be resourceful and creative in selecting TMDL approaches and should learn from the results of similar analytical efforts. The degree of analysis required for each of the components of TMDL development can range from simple, screening-level approaches based on limited data to detailed investigations that might take several months or even years to complete. A variety of interrelated factors affect the degree of analysis in each of these analytical elements. The factors include the type of impairment (e.g., violation of a numeric criterion versus designated or existing use impairment); the physical, biological, and chemical processes occurring in the waterbody and its watershed; the size of the watershed; the number of sources; the data and resources available; and the types and costs of actions needed to implement the TMDL (see Figure 2-2).

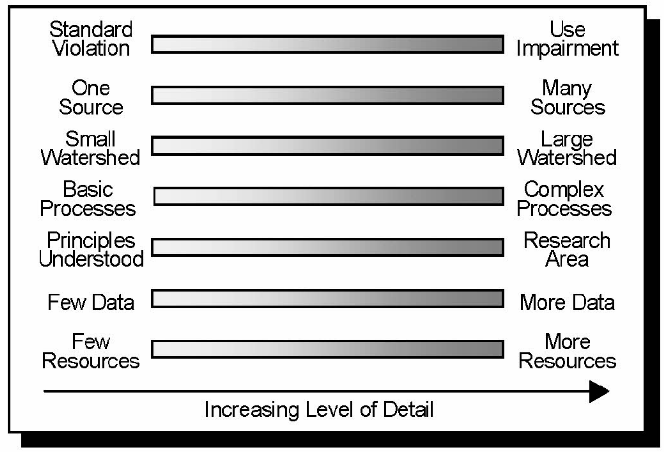


Figure 2-2. Factors influencing the level of detail for the TMDL analysis

Decisions regarding the extent of the analysis must always be made on a site-specific basis as part of a comprehensive problem-solving approach. TMDLs are essentially a problem-solving process to which no "cookbook" approach can be applied. Not only will analyses for different TMDLs studies vary in complexity, but the degree of complexity in the methods used within individual TMDLs might also vary substantially. Screening-level approaches afford cost and time savings, can be applied by a wide range of personnel, and are generally easier to understand than more detailed analyses.

The trade-offs associated with using simple approaches include a potential decrease in predictive accuracy and often an inability to make predictions at fine geographic and time scales (e.g., watershed-scale source predictions versus parcel-by-parcel predictions, and annual estimates versus seasonal estimates). When using simple approaches, these two shortcomings should be considered when determining an appropriate margin of safety.

The advantages of more detailed approaches are presumably an increase in predictive accuracy and greater spatial and temporal resolution. These advantages can translate into greater stakeholder "buy-in" and smaller margins of safety, which usually reduce source management costs. Detailed approaches might be necessary when the screening-level approaches have been tried and have proven ineffective or when it is especially important to "get it right the first time" (e.g., where protection of aquatic life habitat is a TMDL issue). In addition, more detailed approaches might be warranted when there is significant uncertainty regarding whether sediment discharges are attributable to human or to natural sources and the anticipated cost of controls is especially high. However, more detailed approaches are likely to cost more, require more data, and take more time to complete.

Using Sediment Loads Versus Alternative Approaches for Sediment TMDLs

The traditional approach to TMDL formulation is to identify the total capacity of a waterbody for loading of a specific pollutant while meeting water quality standards. This loading capacity is not to be exceeded by the sum of pollutant loads allocated to individual point sources, nonpoint sources, and natural background. Therefore, TMDLs have often been expressed in terms of maximum allowable mass load per unit of time. However, alternative approaches to sediment TMDL analysis might also be appropriate. In many cases, it is difficult or impossible to relate sediment mass loading levels to designated or existing use impacts or to source contributions. These analytical connections can be difficult to draw for several reasons, including the following:

- Sediment yields vary radically at different spatial and temporal scales, not only within a watershed, but across the country, making it difficult to derive meaningful "average" sediment conditions.
- Sediments are a natural part of all waterbody environments, and it can be difficult to determine whether too much or too little mass loading is expected to occur in the future and how sediment loads compare to natural or background conditions.
- A significant level of uncertainty is associated with sediment delivery, storage, and transport estimates.

Fortunately, it is acceptable for TMDLs to be expressed through appropriate measures other than mass loads per time (40 CFR 130.2). It is important to note, however, that some of the limitations associated with mass load approaches, such as high temporal variability, are also present in the alternative approaches and the consequences of these limitations should be assessed and acknowledged. The alternative measures for sediment TMDLs can take several forms, including the following:

- Expression of numeric targets in terms of substrate or channel condition, aquatic biological indicators, or hillslope indicators such as road stream crossings with diversion potential or road culvert sizing. The hillslope indicators and targets should complement in-stream indicators and targets.
- Expression of numeric targets and source allocations in terms of time steps different from daily loadings and as functions of other watershed processes such as precipitation or runoff.
- Expression of allocations in terms other than loads or load reductions (e.g., specific actions shown to be adequate to result in attainment of TMDL numeric targets and water quality standards).

This protocol discusses a range of pollutant load-based and alternative measures that can be used for sediment TMDLs. In general, the load-based approach to sediment TMDL development is recommended. In cases where this approach is used, numeric targets can be stated in terms that express desired environmental conditions (e.g., suspended sediment concentration or substrate size distribution) while the TMDL itself is expressed in mass-based units. Where alternative approaches are used, analysts should carefully document the basis for the alternative method and explain why a conventional load-based approach is not appropriate.

Sediment TMDL Examples That Illustrate the Range of Appropriate Approaches

Brief summaries of four approved and two hypothetical sediment TMDLs show that a range of viable methods are appropriate for TMDL development and that individual TMDLs often combine relatively complex analysis for some elements with simple analysis for others. In addition, they illustrate several factors that can be important for effective TMDL development, including (1) focusing on implementation of the TMDL, (2) using existing information and adaptive management, and (3) using expert judgment. More detailed case studies are provided in the Appendix.

Sycamore Creek, Michigan

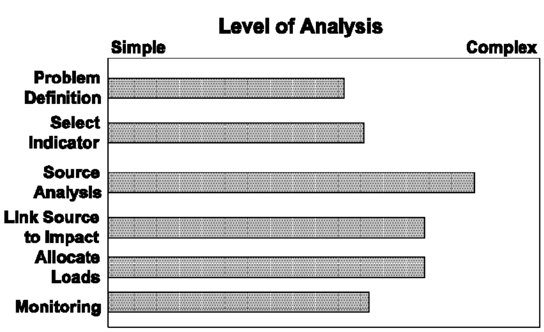
Sycamore Creek is designated for the support of warm water fish, other indigenous aquatic life, and wildlife; total body contact recreation and navigation; and as an industrial and agricultural water supply (USEPA, 1992a). Elevated sediment loadings from agricultural land practices caused significant impacts on aquatic life and habitats in Sycamore Creek and contributed to low dissolved oxygen levels. Modeling results indicated that sediment oxygen demand was the most significant oxygen sink during drought periods. Placement of Sycamore Creek on the state's 303(d) list was supported by in-stream monitoring conducted by the Michigan Department of Natural Resources (MDNR) that revealed multiple violations of water quality standards at seven of eight sampling stations.

MDNR used a quasi-steady-state dissolved oxygen (DO) model to predict DO concentrations in the creek during critical low-flow drought conditions (USEPA, 1992a). Modeling revealed that sediment oxygen demand (SOD) was the most significant DO sink during critical low-flow periods and that respiration by aquatic plants significantly contributed to the oxygen deficit at some locations in the creek (USEPA, 1992a). MDNR determined that nutrients bound to suspended sediment particles were a major source driving the growth of aquatic plants and the subsequent elevated respiration rates in aquatic plants (USEPA, 1992a). Based on these results, MDNR believed that reducing suspended solids loadings to the creek would increase DO concentrations, improve aquatic habitats, and restore the designated uses of the stream (USEPA, 1992a).

Development of a sediment TMDL for Sycamore Creek began with an assessment of the existing sediment loadings to the stream. Rates of average annual sediment loading from nonpoint sources were examined. Primary nonpoint sources of sediment within the watershed included urban runoff, streambank erosion, agricultural fields, and septic tank systems. Site-specific monitoring data, load estimation equations, and nonpoint source loading models were used to estimate suspended solid loads from the most significant sources—agricultural areas, eroding banks, and urban areas (USEPA, 1992a). Modeling efforts established the relationship between in-stream DO levels and SOD. To determine the needed load reductions, it was necessary to link SOD to suspended solid loads. In the absence of models to reliably predict the effects of reducing suspended solids on habitat, aquatic life, or SOD, MDNR assumed a proportional response by SOD rates to reductions in suspended solids loads. Based on this assumption, loading analysis results indicated that a 52 percent reduction in the overall suspended solids loading was necessary to restore the designated uses of the stream (USEPA, 1992a). MDNR has not yet finalized a load allocation scheme for achieving the suspended solids reduction goals. A proposed allocation plan includes reducing agricultural erosion by 56 percent, streambank erosion in organic soils by 100 percent, and loading from urban runoff by 30 percent (USEPA, 1992a).

To determine whether the TMDL will improve conditions to support designated uses and maintain water quality standards, MDNR is monitoring throughout three agricultural subwatersheds that drain to Sycamore Creek.

Sycamore Creek



Water Quality Targets	TMDL/ Allocations	Water Quality Controls
• TSS and DO/SOD relationships • total annual sediment loads	• % reductions by source category as long-term average	• cropland BMPs • bank stabilization

Source Analysis: monitoring data, regression model, urban loading model
Link to Indicators: modeled linkage of suspended sediments and sediment oxygen demand

Data collected from this monitoring program will be used to model storm runoff from agricultural fields, the major land use in the watershed, using the Agricultural Nonpoint Source Model (AGNPS). Future monitoring data collected from these subwatersheds will be used to refine the AGNPS model (USEPA, 1992a).

South Fork Salmon River, Idaho

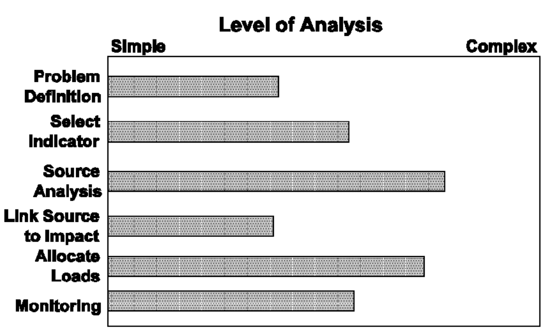
The South Fork Salmon River (SFSR) supports valuable game fish populations of trout, char, and salmon. In recent years, however, fish spawning in the SFSR has sharply declined. Monitoring data collected since the 1960s show that excessive levels of fine sediments entering the river adversely affect salmonid spawning and rearing habitats (USEPA, 1992b). The waters of the SFSR were found to be impaired in a 1988 Idaho Water Quality Report and Nonpoint Source Assessment, which listed three stream segments of the SFSR as impaired due to elevated fine sediment loadings from forestry activities in the basin (USEPA, 1992b). As a result of these findings and public support to restore the beneficial uses, the state of Idaho targeted the waterbody as a high priority for TMDL development.

The TMDL development process for the SFSR included the formation of a consensus team consisting of members from the USFS and USEPA and state representatives. Based on results of the site-specific sediment loading model BOISED, fisheries results, and professional experience in the region, the team developed the following numeric targets for the SFSR: (1) a 5-year mean of 27 percent depth fines by weight, with no single year over 29 percent; (2) a 5-year mean of 32 percent cobble embeddedness, with no single year over 37 percent; or (3) acceptable improving trends in monitored water quality parameters that reestablish the beneficial uses of the SFSR (USEPA, 1992b).

In addition to extensive amounts of monitoring data and the BOISED model, the team also used sediment loading analysis procedures developed during detailed research on erosion and sediment delivery from roads in a watershed in the Boise National Forest to evaluate current conditions in the SFSR watershed. These procedures were used to estimate loads originating from roads, while all other sediment loading estimates were generated using BOISED.

The watershed was divided into units of similar landform, geologic, soil, and vegetative characteristics. Then dominant erosion processes, including surface and mass erosion, were evaluated for each land unit to estimate the sediment yield. Where erosion and sediment yield data were missing, available research data were extrapolated to areas of similar characteristics to predict the effects of various watershed disturbances. The model estimated average annual sediment yields for undisturbed conditions, past activities, and proposed future activities. Although the model results were not regarded as highly reliable in predicting absolute quantities of sediment delivered to the river at a specific time, they were appropriate for comparing alternative management scenarios within the watershed.

South Fork Salmon River



Water Quality Targets	TMDL/ Allocations	Water Quality Controls
• % fine sediments in spawning gravels • cobble embeddedness • 5-yr mean and annual maximum	• 25% overall long-term reduction • specific load reduction estimates for each project	• road improvement projects • slide restoration projects

Source Analysis: BOISED sediment loading model and road erosion estimation method
Link to Indicators: best professional judgment of team

The BOISED model was used in combination with best professional judgment and experience in the area to develop a sediment reduction scheme to meet the numeric criteria developed by the consensus group. Based on these results, a TMDL was established to reduce sediment inputs from anthropogenic activities by 25 percent (USEPA, 1992b). Because of the phased approach of the TMDL, an implementation and monitoring plan was developed to establish reasonable assurances that designated uses would be restored. By 2001, if monitoring determines that salmon spawning has increased to acceptable levels, no change in the program will be needed. If, however, monitoring indicates that designated uses are not being restored, additional recovery projects and methods for designated use attainment will be considered.

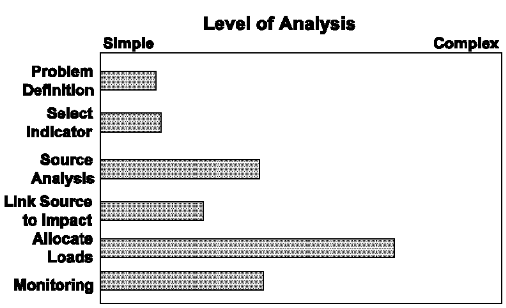
Ninemile Creek, Montana

The Ninemile Creek TMDL illustrates the development of a TMDL based on simple analytical methods to determine numeric targets, sources, and allocations, while focusing available resources on identification of specific source management and restoration practices. Sediment loading from rangeland, bank erosion, and possibly upstream silvicultural activities was believed to be causing impairment of trout spawning. A nonpoint source management project was initiated to select and implement sediment BMPs, and a TMDL was derived based on planning work done for this project. Monitoring data were available for total suspended solids (TSS), streamflow, and redd counts per mile. The numeric targets were based on comparison of spawning redd counts above and below the impacted area and were expressed in terms of redds per mile. The most significant source area for the sediment loadings was determined by evaluating TSS and flow data for a 1-year period at several sampling sites around the study area. Sediment load reduction targets were determined through data evaluation and the best professional judgment of a multiagency team. A detailed set of range management BMPs and bank stabilization actions was identified in concert with landowners, the USFS, and the NRCS. The numeric target and source analysis methods were adequate to guide the development and implementation of a specific set of BMPs and restoration practices, and follow-up monitoring of total sediment loading (using automatic samplers) and annual redd count changes was planned.

Upper Birch Creek, Alaska

The Upper Birch Creek TMDL is an example of a sediment TMDL involving both point and nonpoint sources that is based primarily on relatively simple analysis of available turbidity and TSS monitoring data for the creek and loading sources. The water quality of Upper Birch Creek is affected by discharges from active mines, bank erosion, resuspension of deposited sediments, and runoff from abandoned mine sites. Source water for drinking water, recreation, and aquatic life are affected by these discharges. Monitoring data for suspended and bottom sediments, flow, and biological parameters were collected for more than 20 years. Designated uses were believed to be affected by suspended sediment (turbidity) and by sediment deposition, which affected stream morphology and bed structure. To develop TMDL targets and a source analysis based on sediment loading, the relationship between turbidity and TSS was determined through

Ninemile Creek



Water Quality Targets	TMDL/ Allocations	Water Quality Controls
• 130 redds/mile	• 80% reduction in annual sediment loads	• rangeland BMPs • streambank stabilization

Source Analysis: sediment and flow monitoring data above and below study area
Link to Indicators: BPJ and reference site comparisons

AR0023004

regression analysis. As a result, it was possible to establish numeric targets and TMDL allocations in terms of allowable sediment loading per day.

A careful analysis of critical flow and loading conditions was conducted. After determining the total assimilative capacity, existing nonpoint source contributions were estimated based on comparisons of mined areas with unmined areas. An explicit 10 percent MOS was also provided. It was determined that Upper Birch Creek could meet the turbidity standard in the absence of point source discharges; therefore, needed load reductions would be obtained by curbing discharges from active mines. Wasteload allocations were established in the form of maximum pounds of suspended solids per day per mine.

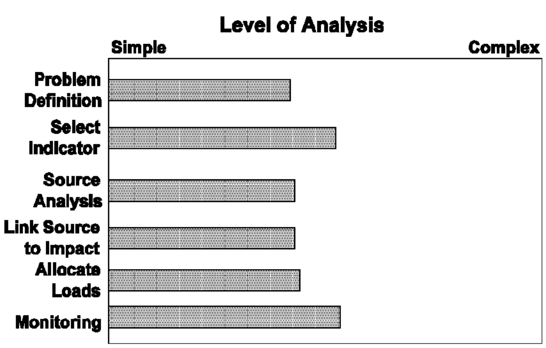
Although the TMDL is focused primarily on attainment of the turbidity standard, channel condition and associated spawning habitat are expected to improve dramatically as well. The follow-up monitoring plan focuses on stream channel sediment parameters as well as suspended sediment indicators. In addition, the TMDL plan includes a discussion of control actions and schedules, which assists in assessing implementation of controls.

Chris Creek (hypothetical)

The "Chris Creek" example is a hypothetical TMDL based on three TMDLs currently under development in northern California. This example illustrates a variety of creative approaches to TMDL interpretation and analysis where watersheds are dominated by infrequent, high-magnitude runoff events and where sediment impacts, sources, and control needs are difficult to characterize. Chris Creek is a steep forested watershed in which hillslopes are unstable and erosion-prone. Chris Creek provides spawning and rearing habitat for several threatened salmonid species, but habitat quality is degraded due to excessive sedimentation of spawning gravels and rearing pools. Historical land use activities and periodic extreme storms and associated sediment erosion effects are responsible for much of the current in-stream sedimentation problem. Silviculture and livestock grazing are the predominant land uses in the watershed and are believed to be contributing additional sediment to the stream. The TMDL is being developed concurrently with development of fish habitat protection and watershed-scale timber production plans by fisheries and land management agencies. In addition, the TMDL is addressing temperature-related habitat impairment.

Extensive data are not available for Chris Creek, but limited sampling of substrate sediment composition and fish counts has been completed. More extensive land use and management information is available (e.g., road inventories, timber harvest records and plans, and landslide mapping). Extensive analysis of fish habitat conditions, sediment sources, and sediment management actions has been conducted in neighboring watersheds. In addition, extensive research on salmonid habitat requirements has been published. The analysts decided that multiple environmental indicators and associated

Upper Birch Creek



Water Quality Targets	TMDL/ Allocations	Water Quality Controls
1. total suspended solids load per day	2. maximum TSS load per day per mine (PS) 3. TSS load per day total (NPS) 4. explicit 10% margin of safety	• NPDES permit limits
Source Analysis: regression analysis of ambient and discharger monitoring data ***Link to Indicators:*** analysis of monitoring data, regression analysis of TSS-turbidity relationship		

targets would be needed for Chris Creek because no single indicator was believed to provide a reliable basis for measuring stream response to changes in management activity and restoration actions (Reiser and Bradley, 1992; Young et al., 1991). Numeric targets for Chris Creek include both "core" and "secondary" indicators. The core indicators are to provide the primary indicators for measuring TMDL effectiveness; the secondary indicators are intended to complement the core indicators and provide additional information for reevaluating the TMDL in the future. The core indicators and associated targets were selected based on how closely they fit the sediment-habitat issues of concern for Chris Creek and how well they are supported by research literature and local "on the ground" experience.

Both in-stream and hillslope indicators were selected. In-stream indicators were determined to be necessary to be able to establish relationships between stream sediment levels and habitat functions. Hillslope indicators were selected to provide a means of directly measuring reductions in hillslope erosion, which in-stream indicators might not be able to identify effectively. The core in-stream indicators included residual pool volume occupied by fine sediments (V*), median sediment size (D_{50}), and invertebrate counts (Lisle and Hilton, 1992; Peterson et al., 1992; Reiser and Bjorn, 1979). Core hillslope indicators include miles of unimproved roads per square mile and road-related landslides. Target values for each indicator were selected by consensus of an expert team based on data from reference watersheds, and literature reviews. Secondary indicators included width-depth ratios, volume of large woody debris per stream mile, and salmonid counts.

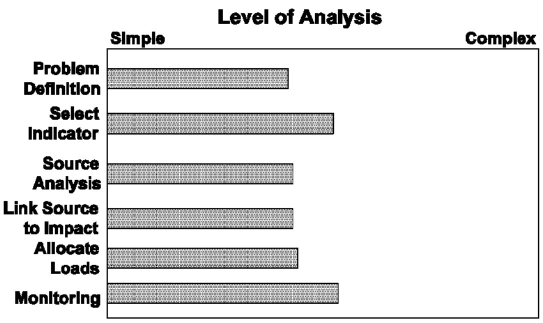
Because Chris Creek is fairly large (200 square miles), remote analysis methods supplemented by field verification were used to develop rough absolute and relative estimates of sediment source contributions to Chris Creek. A screening-level analysis of sequential air photo coverages was used to identify erosion features and channel changes over time. An initial sediment source inventory was conducted by stratifying the watershed into areas of similar geology, slope, and vegetation cover. Simple erosion estimates were developed for each major source category in each stratified land area using literature-based relationships.

Field verification was conducted to assess whether these simple "remote" estimates were reasonable and to ensure accounting of all major sediment sources. Particular attention was paid to evaluating erosion potential associated with road-related erosion because roads were believed to be one of the main erosion sources. Field evaluations of road erosion hazards and estimates of erosion potential were made for a subset of roads in the watersheds. The results were extrapolated for the entire watershed based on the distribution of road types determined through air photo analysis. The erosion estimates from roads and other sources were summed. Finally, it was assumed that all eroded sediment would reach the stream. This conservative assumption was adopted for three reasons:

- Lack of site-specific information on sediment delivery.
- Because roads are a major source and literature sediment delivery values are typically very high.
- To include an implicit margin of safety in the source loading estimate.

TMDL allocations were developed in two steps. First, sediment reduction needs were estimated by comparing existing values for core indicators with target values established by the team. Based on this comparison, the team established an overall percentage reduction target. Based largely on the team's best professional judgment, allocations were established by source category. The allocations considered the relative sediment contributions from each source, the proximity of these sources to the stream, and the feasibility and cost of reducing erosion from different sources. The allocation section of the TMDL was complemented by the development of a detailed set of implementation recommendations for consideration by involved landowners and land management agencies. Finally, a detailed monitoring plan was developed to track each of the core and secondary indicators. An adaptive management schedule for reviewing project results was established, with reviews scheduled every 5 years. In the second phase of the project, the developers will consider whether more detailed geomorphic analysis and stream restoration planning are needed. If fish habitat quality begins to recover in response to continuing reductions in sediment inputs, more intensive analysis and restoration might not be needed.

"Chris Creek"



Water Quality Targets	TMDL/ Allocations	Water Quality Controls
• median sediment size • V* (pool sediment indicator) • road-related landslides • road density	• % reductions by category in long-term annual averages	• forestry BMPs • road improvements
Source Analysis: rapid sediment budget, measurement of erosion potential from roads ***Link to Indicators***: set erosion reduction need (percentage) in proportion to degree existing targets exceed target levels		

Wendell Creek (hypothetical)

The "Wendell Creek" TMDL example is based on several watershed analysis and restoration planning efforts conducted in the western United States that incorporated relatively complex geomorphic analysis and sediment budgeting methods to develop numeric targets, estimate source contributions, and allocate loads. Wendell Creek drains a 150-square-mile watershed in which livestock grazing is the predominant land use. Aquatic habitat in Wendell Creek is impaired by high-magnitude sediment loading associated with infrequent flood events and landslides. As a result of these sedimentation and flooding events, the stream channel has changed from a relatively deep, meandering channel that provided plentiful spawning gravels and deep rearing pools to a broad, shallow, braided channel with poor gravels and few pools. These changes in stream channel structure were documented through comparative analysis of sequential air photo coverages and intensive monitoring of stream channel structure, including the following:

- Width-depth ratios
- Channel cross sections
- Longitudinal profiles
- Meander pattern and sinuosity
- Particle size distributions
- Pool frequency and depth
- Streambank recession rates in key erosion areas

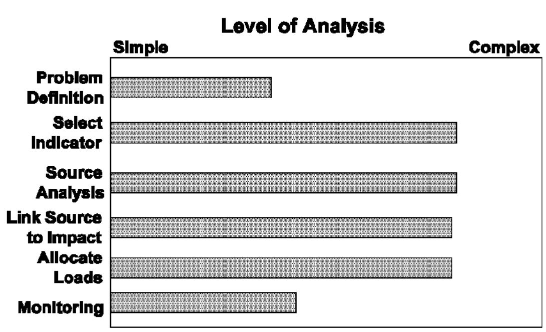
In addition, flow measurements were taken along with suspended and bedload sediment samples at five locations in the watershed during times of high, moderate, and low flow. The sample sites were below junctions with major tributaries and at the mouth of the creek. Numeric targets were developed by comparing geomorphic indicator values for Wendell Creek with values obtained in neighboring Little Deer Creek, which supports good fisheries and is believed to be relatively unimpaired. A sediment budget was prepared based on several types of analyses. First, sediment rating curves were developed for each of the sample stations and used to estimate total annual sediment loads at each station. Annual loads for each station were compared to gain an understanding of relative contributions from each tributary and from streambank erosion. The annual load estimates were also used to derive an initial estimate of in-channel sediment storage between stations and net outflow from the watershed. A sediment budget was also developed for neighboring Little Deer Creek for purposes of identifying relatively natural sediment discharge conditions. The analysts obtained a more detailed understanding of key sediment sources by developing independent estimates of erosion quantities from three major sediment sources of concern identified during initial stream surveys. Sheet and rill erosion from rangeland was estimated through the application of a model based on the Revised Universal Soil Loss Equation (RUSLE). Expected future erosion from five active landslide areas was estimated based on direct measurement of slide volumes and was assumed to eventually enter the stream system in response to high-magnitude runoff events. Finally, erosion from road surfaces was estimated by identifying drainage crossings prone to failure and estimating volumes of sediment that would be discharged if these crossings failed during high-magnitude storms. Because land use, landslide, and road networks were mapped for Wendell Creek watershed, the analysts stratified the results of the rangeland, landslide, and road erosion estimates by watershed and used the results as an independent check on the tributary-based sediment budgets developed through the rating curve approach. The comparison indicated that the source estimates by watershed were accurate within a factor of 2. The in-stream targets were linked with the source analysis in two ways. First, the analysis team estimated the degree of annual sediment reduction needed based on a comparison of annual tons of sediment yield per acre-foot of discharge for Wendell Creek and Little Deer Creek. Second, existing geomorphic indicator values for Wendell Creek were compared with geomorphic conditions in Little Deer Creek.

Based on the professional judgment of the team, it was determined that reduction of sediment loads to Wendell Creek to the levels present in Little Deer Creek was infeasible and that such reductions would not be adequate to restore aquatic life uses in Wendell Creek. Therefore, the team devised plans that called for substantial sediment source reductions to be carried out through implementation of rangeland BMPs, stabilization of two key landslides near the channel, and road network upgrades (principally upgrades of stream crossings that were vulnerable to failure). In addition, the team recommended several streambank stabilization projects in the areas most affected by bank erosion. TMDL allocations were expressed in terms of average annual loads from each tributary and from bank erosion in key reaches of the main stem of Wendell Creek (based on 5-year rolling averages). In addition, key loading sources needing attention in each tributary were identified by location, although quantitative load allocations were not established for each source location. In addition to identifying specific bank stabilization projects needed, the implementation plan developed concurrent with the TMDL identified general types of rangeland BMPs that should be considered and established a process for BMP installation through cooperative efforts of landowners, NRCS, and BLM. Finally, a monitoring program was established to ensure that progress is being made to implement needed BMPs and restoration projects.

Conclusions

These six case study examples illustrate that a range of viable methods are available for developing sediment TMDLs. In addition, they illustrate several factors that can be important for effective TMDL development, including focusing on implementation, using existing information and adaptive management, and using expert judgment.

"Wendell Creek"



Water Quality Targets	TMDL/ Allocations	Water Quality Controls
• width:depth ratios • longitudinal profile (deviation) • geometric mean particle size	• average annual loads by tributary (5-year average)	• rangeland BMPs • bank stabilization • slide stabilization • road improvements

Source Analysis: sediment rating curves, sediment budget, RUSLE, direct volume measurement
Link to Indicators: comparison to reference site sediment budget, geomorphic factors, and best professional judgment

Focusing on implementation

Projects that focus on implementation planning (and for which TMDLs are a by-product) can often use less complex TMDL methods because specific implementation actions can be identified, agreed to, and implemented without controversy (e.g., Ninemile Creek, Montana). Projects where implementation actions are unclear, controversial, or expensive benefit from more detailed TMDL analysis.

Using existing information and adaptive management

Each of these projects made use of existing information and did not assume that extensive new data were necessary. The wide range of methods for establishing sediment TMDLs allows screening-level analyses that provide the framework for targeting implementation actions while collecting more data for any future TMDL evaluations or revisions.

Using expert judgment

In many cases, sediment TMDL elements can be completed through the use of expert interpretation of available information. Since "off the shelf" models and methods are not usually available for sediment TMDLs, sound judgment is critical to project success. Many projects make productive use of expert teams from different disciplines, including fisheries biologists, geologists, hydrologists, geomorphologists, engineers, and land management professionals. This approach works well for TMDLs in controversial settings and often benefits greatly from the inclusion of a professional facilitator.

UTILITY OF ALTERNATIVE SEDIMENT ANALYSIS FRAMEWORKS AND METHODS FOR TMDL DEVELOPMENT

Several frameworks and methods have been used by agencies, landowners, and resource professionals to evaluate sediment processes and associated impacts on designated uses. Commonly used examples include Federal Watershed Analysis (Regional Ecosystem Office, 1995), Washington State's Timber, Fish and Wildlife (TFW) process (Washington Forest Practices Board, 1994) and BLM's Proper Functioning Condition process (USDOI-BLM, 1993/1995). Many of these methods can be used to facilitate TMDL development. In particular, these approaches can often be used to

- Characterize existing conditions and assist in problem definition and cumulative impact analysis.
- Assist in defining acceptable levels of sediment loading (numeric targets).
- Focus the source analysis on critical locations and categories of sediment sources.
- Highlight areas with similar conditions.
- Assist in defining cause-and-effect relationships among watershed processes (for target development, source analysis, and linkage).
- Identify conflicting concerns that could limit the effectiveness of proposed solutions.

Commonly used and recently developed frameworks and methods do not always address the full range of TMDL elements or cannot always generate results precise enough for TMDL purposes. (See Reid [1997] analysis of the Federal Watershed Analysis and the Washington State TFW process.) Table 2-1 provides a summary analysis of several frameworks and methods, indicating the TMDL elements addressed and the main advantages and disadvantages for TMDL application. Analysts are encouraged to make use of other available sediment analysis frameworks and methods and completed projects to reduce the time and cost associated with TMDL development as well as to increase opportunities for integration of TMDLs with other assessment and sediment management programs. However, the analyst should carefully consider whether and under what circumstances each approach will yield results appropriate for individual TMDL elements.

RECOMMENDED READING

(Note that the full list of references for this chapter is included at the end of this document.)

Dunne, T., and L.B. Leopold. 1978. *Water in Environmental Planning*. W.H. Freeman and Co., San Francisco, CA.

Waters, T.F. 1995. *Sediment in streams—Sources, biological effects, and control*. American Fisheries Society Monograph 7. American Fisheries Society, Bethesda, MD.

Table 2-1. Utility of watershed assessment frameworks and methods for sediment TMDL analysis.

Framework/ Method (Source)	Useful In Developing: Problem ID	Numeric Targets	Source Analysis	Linkage	Allocation	Monitoring	Assembling	Advantages	Disadvantages
Washington State Timber, Fish & Wildlife (TFW) (Washington Forest Practices Board, 1994)	★	✔	★		★	✔		• Holistic view of past cumulative effects of watershed processes • Detailed protocol uses expert input in structured approach • Helps plan forest BMPs	• Does not evaluate future cumulative effects • Analysis techniques not fully tested • Quantitative results may not be usable for TMDL elements
Rapid Sediment Budgeting (Reid and Dunne, 1996)	★		★		✔	✔		• Flexible framework for evaluating different sediment sources with different methods at watershed scale • Yields quantitative results • Relatively fast and inexpensive • Not highly data-intensive	• As general methods guidance, does not provide specific "recipe" • Provides no clear linkages to designated or existing use analysis or development of sediment management practices
Ecosystem Analysis at the Watershed Scale (Regional Ecosystem Office, 1995)	★	✔	✔		✔			• Flexible enough to be tailored to specific settings/watershed issues • Evaluates upland and aquatic resource issues along with economic, cultural, and social issues • Many watershed assessments (WAs) have been completed	• Actual WA approaches vary • Aquatics analysis often cursory • Different components are poorly synthesized in individual WAs • Often provide inadequate basis for specific source management
Watershed Hydrologic Conditional Assessment (USDA Forest Service, 1996)	★	★	★		✔			• Specific method to assess physical processes affecting water quality • Yields quantitative evaluations of condition and recovery potential	• New method, not yet widely used • Basis for connections between process analysis and recovery potential analysis unclear
Stream Typing Hydro-Geomorphic Analysis (Rosgen, 1996)	✔	✔	✔			✔		• Organization by stream types provides framework for assessing stream behavior under stress • Helps assess recovery potential and need for restoration action	• Data-intensive • Ability to predict stream behavior or habitat quality based on existing stream type unvalidated • Does not address all sources
Proper Functioning Condition (USDOI-BLM, 1993/1995)	★					✔		• Rapid method for assessing stream condition, identifying nearby sediment sources, and setting priorities for further analysis • Widely used	• Does not yield rigorous quantitative inputs for TMDL • Unvalidated as predictive tool • Often does not view entire watershed; focuses on a few reaches

✔ Sometimes ★ Usually

Problem Identification

Objective: Identify background information and establish a strategy for specific 303(d) listed waters that will guide the overall TMDL development process. Summarize the sediment-related impairment(s), geographic setting and scale, pollutant sources of concern, and other information needed to guide the overall TMDL development process and provide a preliminary assessment of the complexity of the TMDL (what approaches are justified and where resources should be focused).

Procedure: Inventory and collect data and information needed to develop the TMDL. Information collected should include an identification of the degree and type of water quality standards impairment and preliminary identification of sources, numeric targets, proposed analytical methods, data needs, resources required, and possible management and control techniques. Interview watershed stakeholders and local, state, tribal, and federal agency staff to identify information relevant to the waterbody and its watershed. Establish plans for incorporating public involvement into the development of the TMDL. Revise the problem definition as new information is obtained during TMDL development.

OVERVIEW

To develop a TMDL, it is necessary to formulate a strategy that addresses the causes and potential sources of the water quality impairment and available management options. The characterization of the causes and sources should be an extension of the process originally used to place the waterbody on the 303(d) list. Typically, the impairment that caused the listing is related to water quality standards that are being violated—either pollutant concentrations that exceed numeric criteria or waterbody conditions that do not match those specified by narrative criteria or do not support the designated use. Most sediment-related 303(d) listings are based on exceedances of narrative water quality standards that state that waters should be free from suspended or deposited sediments at levels detrimental to designated uses, including aquatic life, water supply, and recreation. In many cases, the problem itself will be self-evident and its identification will be relatively straightforward. In other cases, the complexity of the system might make it more difficult to definitively state the relationship between the sediment sources and the impairment.

Key Questions to Consider for Linkage of Water Quality Targets and Sources

1. What are the designated uses and associated impairments?
2. What data are readily available?
3. What is the geographic setting of the TMDL?
4. What temporal considerations affect the TMDL?
5. What are the sediment sources and how do they affect water quality?
6. What margin of safety and uncertainty issues must be considered? What level of accuracy is needed?
7. What are potential control options?
8. What is the problem?
9. What changes does the proposed rule speak to?

The following key questions should be addressed during this initial strategy-forming stage. Answering these questions results in defining the approach for developing the TMDL. A problem statement based on this problem identification analysis is an important part of the TMDL document because it relates the TMDL to the 303(d) listing and describes the context of the TMDL, thereby making the TMDL more understandable and useful for implementation planning.

KEY QUESTIONS TO CONSIDER FOR PROBLEM IDENTIFICATION

1. What are the designated uses and associated impairments?

The goal of developing and implementing a TMDL is to attain and maintain state water quality standards. With that in mind, analysts should stay focused on addressing the sediment-related problem interfering with the designated uses. Some examples of how sediment impairs designated or existing uses are listed in Table 3-1. Identification of the designated uses being impaired should include answers to the following:

- Are water quality standards for sediment expressed as narrative or numeric criteria?

- What water quality standards violation caused the listing? What data or qualitative analyses were used to support this decision?
- Where in the waterbody are designated uses supported and where are they impaired?
- What are the critical conditions, in terms of flow and season of the year, during which designated uses are not supported?
- How do sediments affect the designated uses of concern? (For example, do bottom sediments clog spawning gravels? Does cloudy water create a swimming hazard?)
- How are quantifiable targets determined to interpret narrative water quality criteria?

2. What data are readily available?

To the greatest extent possible, the problem identification should be prepared based on currently available information, including water quality monitoring data, watershed analyses, best professional judgment, information from the public, and any previous studies of the waterbody (e.g., state and federal agency reports, university-sponsored studies, environmental organizations). Ideally, these data will provide insight into the nature of the impairment, potential sediment sources, and the pathways by which sediments enter the waterbody. Compilation of data necessary for TMDL development should begin during the problem identification stage. These data are likely to include the following:

- Water quality measurements (e.g., TSS, turbidity, bedload composition).
- Waterbody size and shape information (e.g., volume, depth, area, length, channel structure, stream type).
- Biological information (e.g., fish, invertebrate, and riparian vegetation information).

Table 3-1. Examples of sediment impacts on designated or existing use categories

Type	Resource Problem	Sediment Issue
Aquatic Life		
Fish	Adult migration	Passage barriers
	Spawning	Cobble/gravel burial or scour
	Fry emergence	Turbidity/suspended sediment
	Juvenile rearing	Aggradation/scour
	Escapement	Changed channel form
	Winter rearing habitat	Loss of riparian vegetation
	Reduced or hidden food supply	Reduced interstitial dissolved oxygen due to filling of substrate with fines
Invertebrates	Reduced diversity, population density	Filling of substrate with fines Loss of riparian vegetation
Amphibians	Larval development	Filling of substrate with fines
Drinking Water	Reduced reservoir capacity Poor taste/appearance Intakes clogged Impaired treatment	Sediment deposition Turbidity Total suspended solids Aggradation or scour (disturbs intakes)
Recreation/Aesthetics	Cloudy water Channel modification impairs fishing, swimming, rafting	Turbidity Channel modification Pool filling
Agriculture	Fouled pumps Livestock watering Loss of reservoir capacity	Suspended sediment Turbidity too high to drink water Sediment mass loads
Industrial	Process water Cooling water	Suspended sediment fouls equipment TSS too high to treat water
Navigation	Navigation channel changes	Sediment deposition

- Waterbody flow and runoff information, including irrigation return flows.
- Watershed land uses, land use issues, and history.
- Processes of concern (e.g., surface erosion and runoff, bank erosion, landslide features).
- Temperature and precipitation data.
- Soil surveys and geologic information.
- Topographic information.
- Information on local contacts.
- Past studies/surveys.

Maps of the watershed will also be invaluable. Maps can be hard copies, such as USGS quad maps, or (if available) electronic files for geographic information systems (GIS). If possible, point sources, known nonpoint sources, land uses, areas of geologic instability, and road networks should be identified on these maps to provide an overview of the watershed and to identify priority areas for sediment loading caused by human activities.

Photographs, both aerial and landscape, are also very useful for evaluating sediment sources, sediment deposition, and changes in geomorphic/channel features over time. If possible, analysts should obtain multiple air photography sets for the watershed as far back as photo records are available to facilitate time-series comparisons. Photographs from the ground, although less useful, can sometimes provide a qualitative assessment of channel changes over time.

Information on related assessment and planning efforts in the study area should also be collected. Coordinating TMDL development with similar efforts often reduces TMDL analysis costs, increases stakeholder participation and support, and improves the outlook for timely implementation of needed sediment control or restoration actions. Examples of related efforts that should be identified include the following:

- State, local, or landowner-developed watershed management plans.
- NRCS conservation plans, EQUIP projects, and Public Law 83-566 small watershed plans.
- Land management agency assessment or land use plans (e.g., Federal Ecosystem Management Team [FEMAT] watershed analyses or BLM proper functioning condition assessments).
- Nonpoint source management projects developed with Clean Water Act (CWA) section 319 grants.
- Clean Lakes program projects developed with CWA section 314 grants.
- Storm water management plans and permits.
- Habitat conservation plans developed under the Endangered Species Act.
- Comprehensive monitoring efforts (e.g., National Water Quality Assessment [NAWQA] and Environmental Monitoring and Assessment Program [EMAP] projects).

Missing the Mark With Problem Definition

A recent analysis of sediment water quality issues in a western river system illustrates the importance of careful problem definition. In that analysis, an assumption was made that the key limiting factor potentially impairing anadromous fish habitat quality was the adverse effect of fine sediments in spawning gravels on egg survival and fry emergence. The analyst evaluated data on mean sediment particle sizes in river gravels in relationship to graphs developed by fisheries biologists, which related mean particle size to fish fry survival to emergence. The analysis showed that given the existing mean particle size conditions, over 80 percent survival to emergence was expected. The analysis concluded that fish habitat was in good condition. A different analysis of sediment conditions in the same river system had different results. That analysis found a bivariate particle size distribution, with large amounts of very fine sand and very large rocks present in the system. The habitat problem found in the second analysis was not too many fine sediments, but rather insufficient gravels suitable for spawning redds (egg pockets). Because fish could not find adequate gravels of appropriate size, spawning success rates were very low. The initial analysis had misdefined the primary problem as egg survival and fry emergence, missing the key problem of spawning impairment.

3. What is the geographic setting of the TMDL?

TMDLs can be developed to address a variety of geographic scales, including specific stream reaches or watersheds ranging from several square miles in size to well over 1,000 square miles. The geographic scale of the TMDL will primarily be a function of the impairment that prompted the waterbody listing, the type of waterbody impaired, the spatial distribution of use impairments, sediment source locations, and the scale of similar assessment and planning efforts under way for the waterbody.

Where large watersheds or long stream segments have been targeted for TMDL development, it might be appropriate to divide the watershed into smaller analytical units. For example, although the entire Sycamore Creek, Michigan, watershed (106 mi^2) was targeted for TMDLs, one phase of the project focused on the 37-mi^2 subwatershed of greatest concern. Within this smaller subwatershed, the study area was further stratified by source category (e.g., agricultural, urban, bank erosion) to apply different erosion estimation methods for each source category. Sediment TMDLs can be developed at virtually any scale that is hydrologically meaningful (e.g., whole drainage units or reaches) and analytically tractable (methods are available to develop reasonably accurate TMDLs).

The selection of TMDL scale may involve trade-offs between comprehensiveness in addressing all designated use and source issues of concern and accuracy in the analysis (Bisson et al., 1997; MacDonald, 1992). Table 3-2 summarizes the advantages and disadvantages of developing TMDLs for larger (greater than 50 mi^2) and smaller (less than 50 mi^2) watersheds.

Where relatively large watersheds are selected for TMDL analysis, sediment transport and in-channel storage may become more important to the analysis as compared to smaller watersheds where sediment sources and in-stream areas of impact are closer together. Analysis of sediment fate and transport is often needed to determine what happens to sediments once delivered to streams and rivers. For example, fate and transport analysis helps to determine how quickly sediments move through the system, how much sediment remains behind, and under what hydrological conditions sediments are deposited at channel locations of concern. By accounting for sediment transport out of the system, it might be possible to allow larger sediment loadings and still protect designated uses of concern.

Although extensive experience in sediment fate and transport analysis has been gained in many parts of the country, available methods are relatively time- and resource-intensive. Analysts who are considering incorporating more sophisticated analysis of sediment fate and transport into a TMDL are advised to consult with a qualified hydrologist or geomorphologist. It is beyond the scope of this protocol to fully explore sediment transport analysis methods, but several published sources provide useful guidance in the selection of sediment transport analysis methods (e.g., Gomez and Church, 1989; Reid and Dunne, 1996; Vanoni, 1975; White et al., 1978).

Recommendations: Where the designated use impairments are located at the bottom of a watershed (e.g., in a lake, estuary, or lower main stem river), it is often more effective to address the entire watershed at once through the use of less intensive, screening-level assessment methods. To evaluate sediment sources effectively, large study areas can be stratified into smaller analysis units to generate sediment loading estimates and results can then be aggregated at the larger study unit scale (Reid and Dunne, 1996). The TMDL for a large study unit will often need to be developed using the phased approach so that follow-up monitoring can be used to assess the effectiveness of the source reductions and to evaluate the accuracy of the TMDL linkages between sediment sources and impacts. If necessary, more in-depth analysis can be targeted to specific "hot spots" within the watershed that have local problems.

Where impairments occur throughout a watershed, it is recommended that the analysis be conducted for smaller, more homogenous analytical units (subwatersheds). For example, specific impaired river reaches might require detailed TMDLs to address individual sources. If this subwatershed approach is chosen, care should be taken to apply consistent methodologies within a basin from one subwatershed to the next so that an additive approach can eventually be applied to the larger basin.

Table 3-2. Advantages and disadvantages of different TMDL watershed analysis scales

	Large TMDL Study Units (> 50 square miles)	Small TMDL Study Units (< 50 square miles)
Advantages	• Accounts for watershed processes that operate at larger scales • More likely to account for cumulative effects • Avoids need to complete separate studies for multiple tributaries	• Easier to identify and address fine-scale source-impact relationships and to identify needed control actions • Possible to use more accurate, data-intensive methods
Disadvantages	• Confounding variables obscure cause-effect relationships • Numeric target setting is harder for heterogeneous waterbody features • Source estimation is more difficult because land areas are more heterogeneous • Lag time between sediment discharge and in-stream effects is potentialy longer, so effectiveness of source controls is harder to assess • Analysis at coarse scale might cause TMDL to "miss" source-impact relationships at fine scale	• May miss cause-effect relationships detectable only at broad scale (cumulative impacts) • May necessitate many separate TMDL studies in a basin to cover the same area • Main problem may be big river

4. What temporal considerations affect TMDL development?

Sediment TMDLs should consider seasonal and interannual variations in pollutant discharges, receiving water flows, and designated or existing use impacts. Like most nonpoint source pollutants, sediment loadings are not continuous in magnitude or effect and are likely to increase as rainfall, runoff, and/or irrigation return flows increase. However, land management activities (e.g., cultivation) occurring during dry periods set the stage for erosion and sediment delivery when precipitation or irrigation runoff occurs. The seasonal variability of sediment discharges and associated designated or existing use impacts should be considered during each phase of TMDL development.

Sediment impacts occur over different time scales, depending on the designated or existing uses of concern. Some uses (e.g., anadromous fish habitat) are much more sensitive during certain times than at other times (e.g., during the spawning and egg emergence life stages). Other uses are more continuous and consequently are sensitive to excess sediment impacts throughout the year (e.g., drinking water or industrial process water intakes). Finally, some designated or existing uses suffer from cumulative effects of sediment loading over long periods of time (e.g., reservoir storage capacity, which affects water supply).

For many pollutants, TMDLs are developed for a defined "critical flow" regime (usually low flow) when the pollutant is believed to cause the greatest impacts. The TMDL is then defined for this critical flow situation on the assumption that it will be protective during other flow regimes. The critical flow approach might be less useful for sediment TMDLs because sediment impacts can occur long after the time of discharge and sediment delivery and transport can occur under many flow conditions. Analysts should be aware of the flow regimes of concern for sediment TMDLs. Although sediment impacts can be substantial at low flows in some situations (especially in some eastern and midwestern waterbodies), sediment-related impacts are often associated with higher-flow events (e.g., direct effects on aquatic life, water supply intakes). Even if high-flow impacts are insignificant, a TMDL would need to consider flows associated with the time periods in which sediment discharges of concern occur, which are usually relatively high flow, high runoff periods. High flows are considered to be the critical flows of concern for sediment analyses in most situations. In some circumstances, however, it might make sense to consider flows over long periods of time as the "critical" flow for TMDL calculation purposes (e.g., where long-term sediment loads fill reservoirs and reduce storage capacity).

Sediment discharges also vary substantially in their timing, depending primarily on the sources of concern, the watershed geology and landform, and the precipitation/runoff patterns. Some sources are vulnerable to erosion year-round (e.g., bank erosion and continuously cultivated lands); other sources are vulnerable only during and shortly after land-disturbing activities (e.g., timber harvesting or construction activities). In addition, watershed processes that affect the magnitude, duration, and locations of sediment discharges vary greatly over longer temporal scales. For example, sediment transport mechanisms of greatest concern in many watersheds recur relatively frequently, often in conjunction with the bankfull flow event, which may occur every 1 to 5 years (Wolman and Miller, 1960). In contrast, the dominant events contributing to elevated levels of sediment transport and deposition in other basins may occur only in response to infrequent catastrophic events such as landslides or channel-modifying flood events, which generally recur within time scales of several decades to several centuries (e.g., some Northern California coastal watersheds).

Recommendations: The temporal variability of both sediment impacts on designated or existing uses and sediment discharges from different sources indicates that careful consideration should be given to temporal issues in TMDL development. Analysts should assess whether TMDL development methods are capable of accounting for temporal variability in watershed processes. For example, use of suspended sediment or turbidity as a sole TMDL indicator might not be advisable for many watershed settings because these measures are often highly variable through time and difficult to use for trend-monitoring purposes. In watersheds where sediment inputs are highly variable and intensive monitoring is infeasible, these indicators might be incapable of detecting the magnitude of significant changes in sediment delivery and unable to associate sediment discharges with designated or existing use impacts. In such settings, indicators that represent waterbody response to sediment loading over time (e.g., substrate composition indicators or direct measures of sediment loading from key sources) may be preferable. This protocol provides additional guidance related to time scale issues in later chapters.

5. What are the sediment sources and how do they affect water quality?

The analyst should form an initial understanding of the relative magnitude of the various sediment sources during problem identification. This initial source identification can often be based on existing information; however, it is highly recommended that analysts walk portions of streams and visit known or suspected erosion sites if at all possible. The initial source inventory will often be as simple as marking down on a map the locations of known erosion problem areas (e.g., landslide areas, gullies, eroding road features, and stream reaches with eroding banks). A qualitative assessment of the significance of hillslope and in-stream sediment storage, along with changes in channel structure in response to sediment load changes, is also helpful.

In addition to assessing sediment sources, the initial problem definition should begin to identify the specific role that sediments play in affecting designated uses. This analysis is important because many of the impairments associated with sediment loadings can also be caused by other stressors. For example, deposition of fine sediments in pools can be associated with decreased flows in addition to or instead of increased sediment loadings. In addition, dissolved oxygen deficits in spawning gravels, which can impair survival of eggs or fry, can be associated with nutrient loading in addition to fine sediment burial of spawning gravels. Sediments might become the focus of watershed studies simply because they are often the most visible stressor.

Recommendations: Inevitably, the role that sediments play in affecting some waterbody impairments can be determined only by using best professional judgment. Monitoring data can be used to determine current levels of sediments in streams or lakes, but a qualitative judgment is sometimes the best means available to assess the relationship among sediments, flows, channel structure, and other factors. Analysts should use their best judgment and consult with aquatic biologists and other experts as appropriate.

6. What margin of safety and uncertainty issues must be considered? What level of accuracy is needed?

Considerable uncertainty is usually inherent in estimating sediment loading from nonpoint sources, as well as predicting stream channel and designated or existing use responses. The effectiveness of management measures (e.g., agricultural BMPs) in reducing loading varies depending on the location, the severity of the problem being addressed, and other practices being implemented. These uncertainties, however, should not delay development of the TMDL and implementation of control measures. EPA regulations (40 CFR 130.2(g)) state that load allocations for nonpoint sources are "best estimates of the loading which may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading." USEPA (1991a, 1999) advocated the use of a phased approach to TMDL development as a means of addressing these uncertainties. Under the phased approach, load allocations and wasteload allocations are calculated using the best available data and information, recognizing the need for additional monitoring data to determine if the load reductions required by the TMDL lead to attainment of water quality standards. The approach provides for the implementation of the TMDL while additional data are collected to reduce uncertainty.

TMDLs also address uncertainty issues by incorporating a margin of safety (MOS) into the analysis. The MOS is a required component of a TMDL and accounts for the uncertainty about the relationship between pollutant loads and the quality of the receiving waterbody (CWA section 303(d)(1)(c)). The MOS is either implicitly accounted for by choosing conservative assumptions about loading and/or water quality response or explicitly accounted for during the allocation of loads. Table 3-3 lists several approaches available for incorporating an MOS into sediment TMDLs.

During the problem identification process, the analyst should decide at what point in the analysis the MOS will be introduced. Often this decision can be made only by using best professional judgment. The degree of uncertainty associated with the selection and measurement of indicators, source estimates, and water quality response should be factored into this decision, as well as the value of the resource and the anticipated cost of controls. In general, a greater MOS should be included when there is greater uncertainty in the information used to develop the TMDL or when the TMDL is for a high-value water. It might prove feasible to include an MOS in more than one TMDL analytical step. For example, relatively conservative numeric targets and source estimates could be developed that, in combination, create an overall MOS adequate to account for uncertainty in the analysis.

Analysts should consider the level of precision needed in the analysis. As a practical matter, analysts might need to make trade-offs between (1) investing in more precise analysis (presumably at higher cost) of different TMDL elements and providing a smaller MOS (usually providing greater management flexibility) and (2) performing less precise analysis (presumably at lower cost) and providing a larger MOS (presumably constraining land management flexibility).

Many sediment TMDLs can be developed based on existing, readily available data and information. Where sufficient data are not available, TMDLs may be developed based on modeling analysis or on simple "screening-level" analysis in many cases. Where little information about sediment causes and effects is available, it is appropriate to account for the significant

Table 3-3. Approaches for incorporating the MOS into sediment TMDLs

Type of MOS	Available Approaches
Explicit	• Set numeric targets at more conservative levels than analytical results indicate, corresponding to some quantifiable MOS (e.g., 5% below recommended criteria) • Add a safety factor to erosion and/or sediment delivery estimates and expected sediment reductions, corresponding to some quantifiable MOS • Do not allocate a portion of available sediment loading capacity (reserve for MOS)
Implicit	• Use conservative assumptions in derivation of numeric targets • Use conservative assumptions in erosion rates, land recovery rates following disturbance, sediment delivery to waterbodies, and sediment transport rates • Use conservative assumptions in analysis of prospective feasibility of sediment management practices and restoration activities

uncertainty associated with TMDL analysis by providing adequate margins of safety. In some cases, providing larger margins of safety might result in allocations that are not readily achievable. Several approaches are available to address this problem. First, more sophisticated analysis might be appropriate. Where additional data or information is needed to use more complex or data-intensive methods, it might be more cost-effective to gather the information and use the more complex methods than it would be to implement more stringent allocations based on simpler analysis. Where this is the case, a first-phase TMDL can often be developed to provide a basis for further analysis while initiating critical source control or restoration actions.

Because erosion and other key physical processes that affect sediment impacts on designated or existing uses are usually highly variable and difficult to characterize, a significant degree of uncertainty is likely to emerge in sediment TMDL development. Several strategies are available to help address these uncertainties:

- *Use a phased approach.* Clarify that initial TMDLs are based on limited information and that TMDLs and implementation plans will be reviewed and revised in the future based on monitoring results. This approach clearly acknowledges uncertainty and creates a framework for reviewing initial TMDL hypotheses. This strategy is also a good means of identifying information needs.

- *Use multiple numeric targets and a "weight of evidence" approach.* Single-indicator TMDLs are often difficult to relate to designated or existing uses of concern or sediment sources. Multiple indicators that, as a set, are believed to provide a richer basis for interpreting water quality goals and linking goals to source controls can be used in the TMDL. A "weight of evidence" approach would be used to interpret them; that is, evaluations would look at the indicators as a group and would not consider exceedance of one target as proof that a TMDL is not working. If the weight of evidence approach is taken, analysts are advised to clarify at the outset how the responsible agency intends to evaluate TMDL effectiveness as measured by multiple indicators.

- *Use hillslope targets to supplement in-stream targets.* Because it is difficult to associate designated use problems or TMDL indicators and targets with sediment sources, TMDLs can include hillslope targets to supplement (but not supplant) in-stream targets. Hillslope targets provide a TMDL goal that might be easier to associate with sediment source management.

- *Use dynamic indicators and allocation approaches.* Sediment inputs tend to be quite variable across time and space, and TMDL numeric targets and allocations can be expressed in ways that recognize and incorporate the dynamics of watershed processes (e.g., sediment loading targets expressed as a function of flow).

- *Focus load allocations on load reductions related to control actions.* Where load allocations by source are difficult to set but actions needed to reduce loads are well understood, TMDL implementation plans can incorporate more detail on actions to be taken that are believed adequate to attain in-stream targets and meet overall load reduction needs.

7. What are potential control options?

The problem identification should begin to identify potential management alternatives. It is helpful to begin thinking about key sources and the prospective feasibility of controlling erosion from these sources. Improvements already occurring should also be considered when identifying possible control options. In addition, analysts should begin to consider what options will be adequate to address sediment-related impairments. If no obvious level of sediment control will achieve the designated use of the waterbody, the appropriateness of the applicable water quality standards should be evaluated.

If sediment source controls and/or restoration will be able to address the impairment, the problem statement should identify and stress the opportunity to take advantage of other watershed protection efforts. Opportunities include coordinating with various local, state, tribal, territorial, and federal agencies along with private landowners and stakeholder groups to avoid duplicative or contradictory efforts. Other stakeholders should also be encouraged to become involved with development of the TMDL to contribute to the process and to ensure that their concerns are addressed.

8. What is the problem?

A summary problem statement should be drafted to help frame the rest of the TMDL analysis and to help explain the purpose and analytical approach for developing the TMDL to interested parties. The problem statement might need to be revised during development of the TMDL to account for new information. Including the problem statement with the TMDL submission helps clarify the TMDL's scope and setting for readers who are not familiar with the study area.

9. What changes does the proposed rule speak to?

On August 23, 1999, EPA published proposed rules that specify that approvable TMDLs must include at a minimum ten elements. Within the problem identification step, an approvable TMDL will need to include the name and geographic location of the impaired or threatened waterbody for which the TMDL is being established. The TMDL will also need to list the names and geographic locations of the waterbodies upstream of the impaired waterbody that contribute significant amounts of the pollutant for which the TMDL is being established.

RECOMMENDATIONS FOR PROBLEM IDENTIFICATION

- Identify events leading to the 303(d) listing and the data to support the listing. Include any data or anecdotal information that supports qualitative approaches to develop the TMDL.
- Identify the specific role sediment plays in affecting designated or existing uses, usually through qualitative judgment and consultation with experts.
- Contact agency staff responsible for the waterbody listing and collect any information they have available.
- Prepare a flowchart or schematic detailing the processes that might affect impairment of the waterbody.
- Conduct an inventory of available information on point or nonpoint sources using information available from state or local agencies or databases.
- Identify the geographic scale of impairments.
- Identify temporal/seasonal issues affecting things such as discharge rates, receiving water flows, and designated or existing use impacts. Temporal considerations will affect all subsequent stages of TMDL development for sediments.
- Identify and document all ongoing watershed restoration or volunteer monitoring efforts in the watershed.
- Identify any characteristics or future uses of the watershed or waterbody that might affect the TMDL analysis.

RECOMMENDED READING

(Note that the full list of references for this chapter is included at the end of the document.)

USEPA. *TMDL Case Study Series.* <http://www.epa.gov/OWOW/tmdl/case.html>. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1991a. *Guidance for water quality-based decisions: The TMDL process*. EPA 440/4-91-001. U.S. Environmental Protection Agency, Washington, DC. <http://www.epa.gov/owow/tmdl/policy.html>

USEPA. 1995a. *Watershed protection: A statewide approach*. EPA 841-R-95-001. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1995b. *Watershed protection: A project focus*. EPA 841-R-95-003. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1996. *TMDL development cost estimates: Case studies of 14 TMDLs*. EPA-R-96-001. U.S. Environmental Protection Agency, Washington, DC.

USEPA 1999. *Draft guidance for water quality-based decisions: The TMDL process (second edition).* EPA 841-D-99-001. U.S. Environmental Protection Agency, Washington, DC. <http://www.epa.gov/owow/tmdl/proprule.html>

Waters, T.F. 1995. *Sediment in streams—Sources, biological effects, and control*. American Fisheries Society Monograph 7. American Fisheries Society, Bethesda, MD.

Identification of Water Quality Indicators and Target Values

Objective: Identify numeric or measurable indicators and target values that can be used to evaluate the TMDL and the restoration of water quality in the listed waterbody.

Procedure: Select one or more indicators that are appropriate to the waterbody and local conditions. Key factors to consider include both scientific and technical validity, as well as practical issues such as cost and available data. Identify target values for the indicator(s) that represent achievement of water quality standards and are linked (through acceptable technical analysis) to the reason for waterbody listing.

OVERVIEW

To develop a TMDL, it is necessary to establish quantitative measures that can be used to establish the relationship between pollutant sources and their impact on water quality. Such quantitative measures are called indicators in this document. Examples of indicators for a sediment TMDL include maximum turbidity or suspended sediment concentrations, geometric mean size of substrate particles, percentage of pool volume occupied by fine sediments (Lisle and Hilton, 1992), numbers of spawning fish, and percentage of eroding streambanks. Once an indicator has been selected, a target value for that indicator that distinguishes between the impaired and unimpaired state of the waterbody (e.g., no more than 15 percent fine sediment < 0.85 mm, no more than 1000 tons/year sediment yield on average) must be established. Although such discrete impaired or unimpaired cutoffs do not exist in natural systems, quantifiable goals are a necessary component of TMDLs.

Key Questions to Consider for Identification of Water Quality Indicators and Target Values

1. What water quality standard(s) applies to the waterbody?
2. What factors affect indicator selection?
3. What water quality measures could be used as indicators?
4. What are appropriate target values for the chosen indicators?
5. How do the existing values compare to the target value?

This chapter provides background on water quality standards, lists a variety of factors that should be addressed in choosing a TMDL indicator, provides recommendations for setting target values under different circumstances, and explains how to compare existing and target conditions for each indicator. In addition, this chapter identifies target values for the indicator(s) that can be used to track progress toward the restoration of designated uses. Figure 4-1 outlines an approach for linking a water's impairment (e.g., nonattainment of designated use) to a TMDL.

KEY QUESTIONS TO CONSIDER FOR IDENTIFICATION OF WATER QUALITY INDICATORS AND TARGET VALUES

1. What water quality standards apply to the waterbody?

Section 304(a) of the Clean Water Act (CWA), 33 U.S.C. 1314(a)(1), requires EPA to publish and periodically update ambient water quality criteria. These criteria are to ". . . accurately reflect the latest scientific knowledge . . . on the kind and extent of all identifiable effects on health and welfare including, but not limited to, plankton, fish, shellfish, wildlife, plant life . . . which may be expected from the presence of pollutants in any body of water . . . ." Water quality criteria developed under section 304(a) are based solely on data and scientific judgments on the relationship between pollutant concentrations and environmental and human health effects. These recommended criteria provide guidance for states and tribes in adopting water quality standards under section 303(c) of the CWA. States and authorized tribes are responsible for setting water quality standards to protect the physical, biological, and chemical integrity of their waters. The three components of water quality standards include

- Designated uses (such as drinking water supply, aquatic life protection, public recreation).
- Narrative and numeric criteria designed to protect the uses.
- An antidegradation policy.

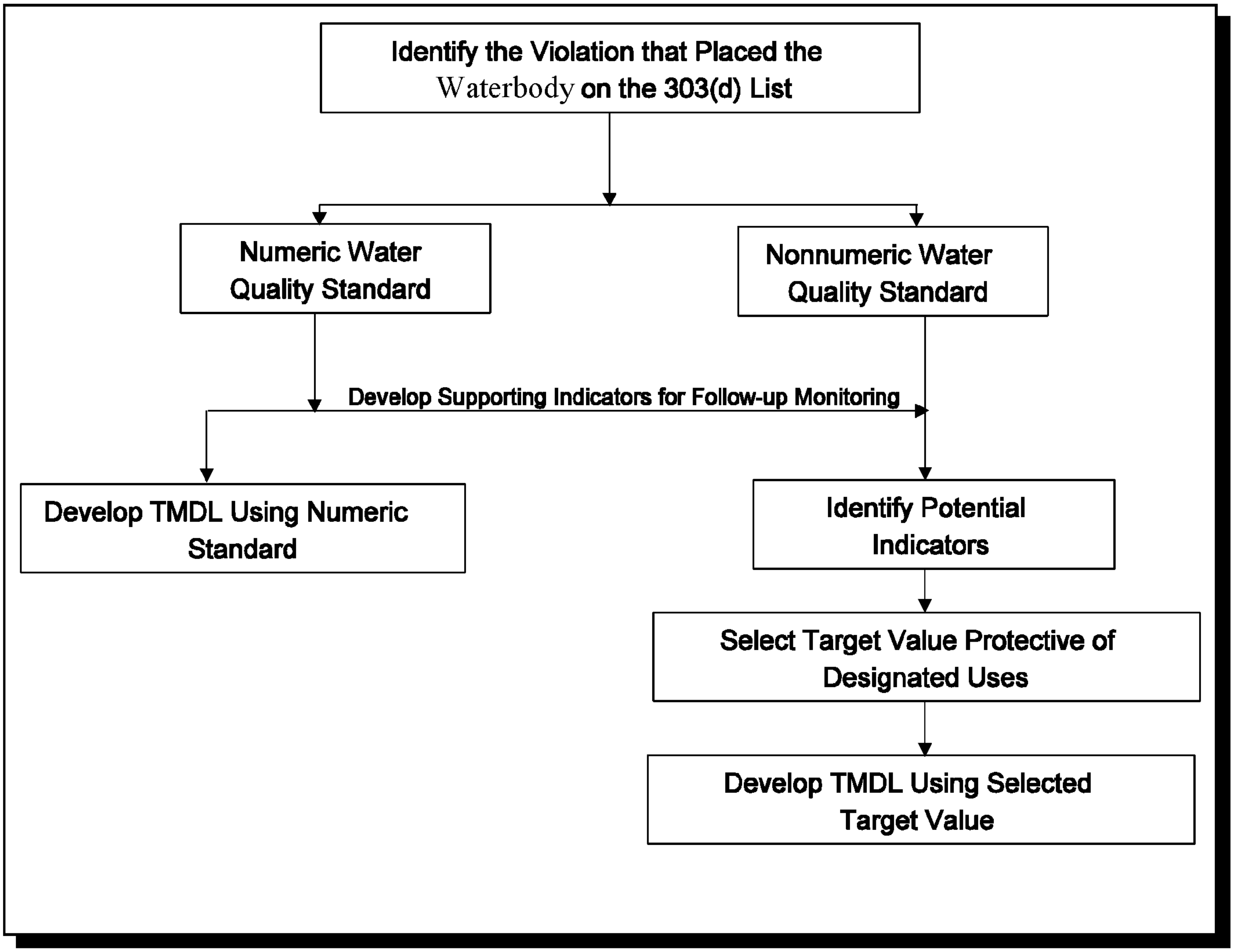


Figure 4-1. Factors for determining indicators and endpoints

For some waters, the indicators and target values needed for TMDL development are already specified as numeric standards in state water quality standards. An example would be a state standard that specifies that turbidity in a river designated for warm water aquatic life support must not exceed 50 nephelometric turbidity units (NTU). However, water quality standards vary considerably from state to state and tribe to tribe and often only narrative standards exist for sediment. In these situations, development of the TMDL will require the identification of one or more appropriate indicators and associated target levels.

Where numeric targets are established for indicators representative of narrative standards, the targets themselves are not water quality standards; rather, they are waterbody-specific interpretations of standards. For example, a TMDL that addresses a narrative standard prohibiting bottom deposits at levels that impair cold water fish reproduction might include numeric channel bottom indicators such as median particle size.

2. What factors affect indicator selection?

A variety of factors will affect the selection of appropriate TMDL indicators. These factors include scientific and technical validity, as well as those associated with practical management considerations. The importance of these factors will vary for each waterbody, depending, for instance, on the time and resources available to develop the TMDL, the availability of existing data, and the designated or existing uses of the waterbody. Final selection of the indicator is based on site-specific requirements.

Scientific or technical validity considerations

Indicators should be logically related to applicable water quality standards and sensitive to the applicable designated uses. Indicators will vary depending on waterbody type. Indicators should also be sensitive to geographic and temporal issues; they should be placed or located where impacts occur. The indicators should also be sensitive to when impacts occur. For example, if water quality is impaired during certain times of the year (e.g., drinking water intake fouling during snowmelt runoff), the indicator should be chosen accordingly (e.g., turbidity during high flows). Indicators should be sensitive to the temporal variability of sediment processes and other driving processes active in the watershed. The inherent temporal variability associated with sediment impacts promotes indicators such as macroinvertebrates or channel conditions, which integrate over longer periods of time.

An indicator should also be helpful in linking pollutant sources to indicator response (e.g., suspended sediment data used as an indicator and as a component of sediment budget development for source analysis). It should also be technically robust; that is, the indicator should be measurable and quantifiable, and measurements of the indicator should be reproducible.

Practical considerations

Data collection should be as economical as possible while still meeting monitoring objectives.
Indicators that can be suitably monitored using cost-effective means should be considered. Indicators should also be feasible to measure, given the capabilities of monitoring personnel and the accessibility of the monitoring site at the times when monitoring needs to be done. Monitoring should introduce as little stress as possible on the designated uses of concern. Since comparability with previously collected information is important, it is helpful to select an indicator that is consistent with already-available data and for which information concerning reference and natural background conditions is available.

The choice of an indicator that is understandable to the public is also desirable. Finally, the indicator should be useful for addressing other pollutants of concern in the analysis. For TMDLs that address pollutants in addition to sediments, some indicators discriminate impacts from the other pollutants as well as from sediment (e.g., biological indicators).

Number of indicators needed for sediment TMDLs

The watershed processes that cause adverse sediment impacts are rarely simple. These processes often vary substantially over time and space, affect designated uses in more than one way (e.g., fish spawning and rearing life stages), and are frequently difficult to relate to specific sediment sources. It is often appropriate to view sediment TMDLs as an iterative approach in which assessment tools, planning decisions, and sediment management actions are each evaluated over time to ensure that they are reasonably accurate and successful in addressing sediment concerns. In many watersheds, more than one indicator and associated numeric target might be appropriate to account for process complexity and the potential lack of certainty regarding the effectiveness of an individual indicator. Table 4-1 lists examples of sediment TMDLs or similar projects that used multiple indicators.

A single indicator might be appropriate in some settings. For example, where drinking water source degradation is the problem, it might be appropriate to establish a single turbidity or suspended solids threshold above which a water treatment plant must shut down or change treatment strategies. It might be possible to link the turbidity or suspended sediment indicator to source analysis and allocation elements that would establish straightforward BMP expectations. With adequate monitoring and review over time, this simple approach could prove effective in protecting drinking water quality. Where the key concern is excessive filling of a reservoir, it might be appropriate to establish an annual average mass loading target above which reservoir life span would be shortened more than stakeholders could accept. Table 4-2 lists several sediment TMDLs that used single indicators.

Table 4-1. Examples of multiple indicators for TMDL targets and similar studies

Waterbody	Indicators Selected	Rationale for Selection
Deep Creek, MT, TMDL (also addresses temperature and flow)	Percent fine sediment < 6.35 mm	Measures sand in spawning gravels
	Number of trout	Direct measure of designated or existing use
	Total suspended solids (TSS) load compared to that of reference stream	Measures direct TSS impact on fish
	Slope of discharge vs. TSS regression	Dynamic TSS measure considers flow variation
	Percent of key reach with erosive banks	Measure of key sediment source
	Increased channel length	Measure of restored channel form
	Minimum flow	Measure of flow-related concern
	Temperature	Direct measure of key fish stressor
South Fork Salmon River, ID, TMDL	Cobble embeddedness	Spawning habitat measure
	Percent fine sediment in gravels	Spawning habitat measure
	Photo point comparisons	Show sediment feature changes
Pittsfield Lake, IL, Nonpoint Source-Clean Lakes Study	Tons of sediment per acre-ft discharge to lake	Dynamic measure of sediment inputs and BMP effectiveness
	Secchi disk depths	Measure lake clarity
	Concentration of total and volatile suspended solids	Measures total and organic sediment concentration
Yager Creek, CA, Draft TMDL	*Core Indicators* • Percent fine sediments < 0.85 mm • Geometric mean particle size (D_{50})	 • Measures fines in spawning gravels • Measure of spawning gravel condition
	Secondary Indicators • Percent fine sediments < 6.4 mm • Residual pool volume occupied by fine sediments (V*) • Width-depth ratios • Macroinvertebrate index • Miles of unimproved roads per mi^2 • Volume of large woody debris per mile	 • Measures sand in spawning gravels • Measures quality of pools used for rearing and refuge from predators • Measures channel recovery • Sensitive measure of habitat quality • Hillslope indicator of key source • Measures key factor influencing stream complexity and pool quality

Table 4-2. Examples of appropriate single-indicator sediment TMDLs

Waterbody	Indicator Selected	Rationale for Selection
Ninemile Creek, MT	Number of trout redds per mile	Direct measure of quality of trout habitat
Lemon Creek, AK	Turbidity under low-flow and high-flow conditions	Direct interpretation of state water quality standards
Humboldt River, NV	Total suspended sediment concentrations	Direct interpretation of state water quality standards

3. What water quality measures could be used as indicators?

This section provides summaries of information on five general categories of potentially useful TMDL indicators. Each summary defines the indicator, reviews its advantages and disadvantages, and makes recommendations for use of the indicator. Following the individual discussions of sediment indicator categories, several tables are presented that compare the suitability of different indicators for TMDL development.

Water column sediment indicators

Two direct indicators and one indirect indicator of sediment load in waterbodies have been used effectively in watershed analysis and TMDL development—suspended sediment, bedload sediment, and turbidity. Suspended sediment refers to the fraction of sediment load suspended in the water column. Bedload sediment refers to the portion of sediment load transported downstream by sliding, rolling, or bounding along the channel bottom. In most cases, sediment particles smaller than 0.1 mm in diameter are transported as suspended load and sediment particles larger than 1 mm are transported as bedload. Particles between 0.1 and 1 mm can be transported either as suspended load or as bedload, depending on hydraulic conditions.

Turbidity is a measure of the amount of light that is scattered or absorbed by a fluid, and it is used as a measure of cloudiness in water. Turbidity is usually associated with suspended sediment, but it can also be caused by the presence of organic matter. Because turbidity is easier to measure than suspended sediment, many studies develop the correlation between TSS and turbidity for sediment load estimation purposes and measure turbidity as the primary indicator. However, analysts should not assume a particular TSS-turbidity correlation without evaluating the local relationship between these variables based, if possible, on multiyear data sets. In addition, as controls are installed, the TSS-turbidity correlation might change.

Suspended sediment and turbidity are associated with aquatic life use degradation in many settings. High levels of suspended sediment can directly affect aquatic species health. Suspended sediment has been widely used as an indicator of sediment accumulation in streambeds, which is also associated with aquatic life impairment (Waters, 1995). In addition, high levels of turbidity or suspended sediment are associated with other use impacts, including contamination of drinking water and industrial process water. Turbidity can also directly affect aquatic species health. For example, turbidity in midwestern smallmouth bass streams can cause young fry to be displaced away from key feeding areas due to loss of visual orientation.

Settings Where Water Column Indicators Are Appropriate

- Where the state has numeric standards for TSS or turbidity.
- Where suspended solids are the principal concern (e.g., drinking water, industrial supply, or recreation).
- Where total sediment loading is a principal concern (e.g., reservoir or estuary situations) or where sediment estimation methods based on suspended and bedload sediment analysis are used.
- Where existing data for these indicators are available and data for other candidate indicators are relatively difficult to obtain (e.g., as surrogate for concern over fine sediment in stream substrate).
- To help distinguish the relative importance of sediment discharge in different stream reaches (e.g., in Sycamore Creek, Michigan, TMDL).
- Where an indicator of sediment water quality upstream and downstream of a project area (e.g., a construction area) is needed.
- When flow data are also available since sediment indicators are generally flow-dependent.

Turbidity or suspended sediment indicators may be used in several ways in TMDL targets. For example, some researchers have noted that some salmonids are adversely affected by highly turbid flows that persist for long periods of time. These researchers have proposed the use of an indicator based on the level of turbidity or suspended sediment associated with adverse fish impacts and the duration of flows above that turbidity/suspended sediment level. It might also prove useful to set turbidity or suspended sediment targets as a function of flow because turbidity would be expected to increase naturally in response to rainfall-runoff events. Early research on tributaries to South Fork Eel River, California, indicates that when adjusted for flow, turbidity levels in a relatively undisturbed reference stream were significantly lower than turbidity levels in a highly disturbed nearby stream.

A variation on the use of suspended sediment concentrations as a direct TMDL indicator is the use of dynamic functions relating suspended sediment loads or concentrations to waterbody flow. This approach was used in the Deep Creek, Montana, TMDL, in which a target was set based on the slope of the regression curve identified by plotting flow against total suspended sediment load. This approach acknowledges the fact that sediment loading often varies substantially as a function of flow (or other driving factors) and better reflects system dynamics than static indicators. However, two sediment curves with the same slope could have significantly different intercepts or curve forms. Where such functional relationships are used in TMDLs, they should be derived based on site-specific or comparable reference data.

Suspended and bedload sedimentation are often evaluated as a component of sediment mass loading studies (e.g., Rosgen, 1996; USDOI-BLM, 1993/1995). Source analysis methods based on suspended and bedload sediment estimation are discussed in Chapter 5. Although bedload analysis is important to sediment mass load studies, bedload sediment has some disadvantages as a TMDL indicator. Bedload transport rates are difficult to measure, are highly variable in space and time, and might not clearly relate to designated use impacts in particular settings (MacDonald et al., 1991). Also, bedload as a proportion of total sediment load varies substantially in different settings (Rosgen, 1996). Significant experience has been gained over the past few years, both in monitoring bedload and in evaluating the accuracy of bedload transport equations (see Reid and Dunne, 1996). Table 4-3 summarizes advantages and disadvantages of various water column sediment indicators.

Measures of water clarity are in some ways the converse of sediment or turbidity indicators. Water clarity is often measured as the water depth at which a Secchi disk or other reflecting material becomes invisible from the surface. This indicator is widely used to measure lake or reservoir clarity.

TMDLs Using Water Column Sediment Indicators

Lemon Creek, AK
Deep Creek, MT
Sycamore Creek, MI
Humboldt River, NV

Recommendations: Water column sediment indicators will be appropriate in many TMDL settings, especially when a numeric water quality standard for TSS or turbidity has been established, or where sediment data will be used as part of the source evaluation method. These indicators should be useful in settings where drinking water, other consumptive uses, and/or recreation are the key designated use issues. In addition, TSS and turbidity might be appropriate indicators in warm water river and reservoir settings encountered in much of the Midwest and South. Where cold water aquatic habitat concerns prevail, these indicators might be useful as secondary indicators to complement streambed and geomorphic indicators, to monitor short-term sediment impacts associated with specific areas, and to estimate sediment yields. Bedload estimates would be most useful as components of total sediment yield estimation methods, and in settings where stream channel changes are associated with bedload sediment processes.

Where TMDLs are developed for lakes or reservoirs, water clarity measures are recommended. Because state water quality standards generally do not set numeric standards for clarity indicators, analysts will need to set targets for clarity as measured by Secchi disks based on historical information or comparison to appropriate reference sites.

If a water column sediment indicator is needed, analysts should consider evaluating the relationship between TSS and turbidity with the hope that a close correlation exists and that turbidity can be used as a cheaper surrogate indicator for TSS. It is usually best to base an analysis of TSS-turbidity correlation on multiyear data since substantial year-to-year variation can occur.

Streambed sediment indicators

A variety of indicators that measure different physical attributes of waterbodies are available. Because so much focus is placed on the adverse effects of sediment aggradation or degradation of streambeds and the associated use impacts on aquatic life, streambed sediment indicators are assessed separately from other stream channel indicators.

Table 4-3. Advantages and disadvantages of water column sediment indicators

Advantages	Disadvantages
• Intuitive appeal to the public (people can see the effect in many circumstances). • Suspended sediment/turbidity impacts are primarily responsible for many designated use impacts. • Because sediment indicator data can also be used to estimate sediment loads (e.g., through use of rating curve methods), the indicator can serve "double duty." • Substantial experience as indicator of sediment problems from crop agriculture, urban runoff, and grazing. • Extensive data are available in some watersheds (especially for suspended sediment).	• Difficulty in associating changes in TSS/turbidity with specific management activities. • Large expected variation in time and space as function of precipitation, hydrograph, and other factors. • Can be difficult or unsafe to measure during high flows. • Difficulty in associating with some designated or existing use issues and establishing target conditions (e.g., habitat quality). • A focus on suspended sediment might not address larger particle sizes that move as bedload. • Bedload is difficult to measure accurately. • Streamflow or discharge usually needs to be measured at the same time for the data to be useful. • Difficult to distinguish human-caused changes.

Streambed sediment quality indicators are based on the theory that excessive or insufficient levels of fine sediments or unnatural substrate size composition directly and indirectly impair aquatic habitat in many ways and during many key life stages. These indicators are used most commonly in settings where cold water fisheries, anadromous fisheries, and associated habitats are of concern. For example, excessive sediment deposition can directly impair spawning success, egg survival to emergence, rearing habitat, and fish escapement from streams, and it can indirectly contribute to problems associated with water temperature increases. The following is a partial list of streambed sediment indicators, the advantages and disadvantages of which are summarized in Table 4-4:

TMDLs Using Streambed Sediment Indicators

Deep Creek, MT
South Fork Salmon River, ID
Garcia River, CA
South Fork Trinity River, CA
Newport Bay, CA
Simpson Timberlands Watersheds, WA (draft)

- Streambed particle size distribution indicators (e.g., percentage of fine sediments less than a certain critical size, geometric mean or median particle size, and the Fredle Index, another measure of central tendency of particle size distribution).
- Streambed coverage measures (e.g., embeddedness, percent sandy or gravel bottom).
- Streambed armoring or transport capacity measures (e.g., comparison of surface versus subsurface particle size; Dietrich et al., 1989).
- Sediment supply measures (e.g., V*, percent of pool volume occupied by fine sediment).

Recommendations: Substrate indicators are only a subset of available geomorphic indicators and are not fully indicative of geomorphic conditions of streams. In many cases it will be appropriate to use substrate indicators in association with other stream channel condition/process indicators and hillslope indicators to ensure that the indicators are sensitive to the entire range of processes affecting sediment impairment.

Geology has a strong influence on substrate size distribution. For example, granitic watersheds often exhibit a natural bimodal size distribution. Therefore, analysts should consider the link between watershed geology and streambed particle size classes.

Settings Where Streambed Sediment Indicators Are Appropriate

- Fine sediment in gravels is causing problems in spawning or egg emergence.
- Sediment accumulation around cobbles or gravels is degrading invertebrate and fish rearing habitat.
- Sediment accumulation in pools impairs hiding and rearing areas (especially where pool formation by woody debris is a secondary process).
- Because of access or high flow problems, only limited sampling is possible.
- Previously collected data are available.

Generally, substrate indicators are recommended for TMDLs focusing on protection of gravel bed aquatic habitat. Specific indicators should be selected based on a thorough understanding of the designated or existing use impacts of primary concern (e.g., use pool indicators where pool quality is a key issue). Because many riffle

Table 4-4. Advantages and disadvantages of streambed sediment indicators.

Advantages	Disadvantages
• There is a relatively high level of experience using them (especially stream bottom particle size distribution indicators) • Indicators effectively integrate sediment loading and transport effects, making it possible to obtain useful results based on annual sampling during the low-flow period. • In some geologic settings, substrate indicators have proven effective in discriminating between disturbed and undisturbed hillslope areas (e.g., Knopp, 1993). • Indicator sampling methods are relatively simple and do not require sophisticated equipment. • Indicators allow for direct empirical association of specific indicators with specific cold-water fish life stage issues (e.g., sediment in riffles as a measure of spawning gravel quality and sediment in pools as a measure of rearing habitat quality). • Particle size is related to macroinvertebrate productivity	• Some methods are difficult to replicate (e.g., cobble embeddedness). • Appropriate target or desired conditions for chosen indicators may vary substantially depending on local watershed and aquatic life characteristics, and indicator target values are not available for many parts of the country. It is inadvisable to apply target values selected in one part of the country to other areas without carefully considering whether the settings are comparable. • Substrate composition is a less important determinant of habitat quality in many parts of the country, including naturally sandy-bottomed streams, low-gradient warm-water fishery streams, most lakes, and geologies with few fines. • Fine sediment accumulation might not be as critical a problem in many cold-water streams in the Midwest and East in which dissolved oxygen conditions are controlled more by ground water upwelling than by stream water infiltration (Waters, 1995). • Some substrate indicators are not easy to understand or to explain to the public. *The following disdvantages are common pitfalls that can be avoided.* • Not all substrate indicators are discriminating of all cold-water aquatic habitat impairment issues. For example, riffle substrate composition indicators might not be effective planning indicators in settings where other limiting factors (e.g., pool filling by fine sediment) prevail. • Focusing on a specific size of fine sediment (e.g., sediment < 0.85 mm) can result in failure to detect problems associated with other sediment sizes. • Not all data for an individual indicator are comparable because different sampling methods are commonly used to characterize particle size distribution (e.g., volumetric vs. gravimetric measurement, wet vs. dry weights or volumes, surface particle size vs. substrate core particle size, and sampling with shovels vs. sampling with McNeil cores).

sediment indicators are closely related statistical measures that can be evaluated without additional sampling, it is recommended that multiple statistical indicators of desirable particle size distribution be used (e.g., percent fines less than 0.85 mm, less than 2 mm, less than 6.4 mm, and/or geometric mean particle size). Selection of multiple particle sizes for analysis is particularly warranted in watersheds where the size distribution of sediments expected to erode as a result of future land management activities is not known (Peterson et al., 1992). When monitoring and evaluating results based on analysis of these indicators, it is important to track and report raw data to facilitate different statistical methods for substrate analysis.

Embeddedness indicators have been applied in Idaho and Montana, particularly in watersheds dominated by sedimentation associated with decomposed granitic soils and where overwintering habitat quality is a primary concern. Embeddedness indicators should be used with caution in other areas, and care should be taken to use quantitative measures of embeddedness to avoid errors associated with qualitative embeddedness measurement techniques (MacDonald et al., 1991). For example, embeddedness may be an inappropriate indicator in steep or very low gradient streams, or in silt- or clay-dominated streams (MacDonald et al., 1991). Finally, embeddedness is not a primary tool in most sediment studies, in part because of its high spatial variability.

Pool indicators (e.g., V*) are useful in many settings both as direct measures of problems associated with pool habitat degradation and possibly as more general indicators of excessive sediment loading in streams (Lisle and Hilton, 1992). Several methods are promising for TMDL development, although caution is advised in applying general "rule of thumb" values in setting pool indicator targets. (For example, setting a V* target of 50 percent for all locations might be inappropriate.) Although it has not been widely used until recently, the V* method holds substantial promise as a TMDL indicator because it is not flow-dependent and it facilitates comparison between streams of different sizes (Lisle and Hilton, 1992).

Although there are few TMDL examples where stream bottom sediment indicators were used, their extensive use in fishery protection projects suggests they will be appropriate in many settings. Whatever method is selected, the same sampling techniques should be used if results are to be compared over time and space.

Other channel condition indicators

Other channel indicators can also support TMDL development because they help evaluate changes in channel shape and structure that might be associated with changes in key sedimentation and hydrologic processes. These indicators can be effective for TMDL development because they can be linked to key designated uses (e.g., cold water habitat) and to land management activities (e.g., livestock grazing along streambanks). By measuring key elements of stream structure, these indicators provide a mechanism for understanding the relative importance of physical process interactions that occur within streams, and for more thoughtfully planning goals for stream management and actions to attain goals (Reid and Dunne, 1996; Rosgen, 1996). The advantages and disadvantages of channel condition indicators are summarized in Table 4-5. Channel condition indicators that might be appropriate for TMDL projects include

TMDLs Using Other Channel Indicators

Deep Creek, MT
Garcia River, CA (draft)

- Pool/riffle ratios
- Cross sections
- Width/depth ratios
- Sinuosity
- Gradient
- Entrenchment
- Thalweg profiles
- Channel scour
- Bank stability (measurement of which considers vegetative cover and erosion features present)
- Pool measures (e.g., residual pool volume, percent pools, and average residual pool depth).

Recommendations: Channel condition indicators can effectively complement other sediment-related indicators in many TMDL projects. Settings where these indicators would be particularly relevant include streams with cold-water habitat degradation issues, drinking water intake issues, flow alteration due to dams, irrigation water conveyance or extensive water diversions, and/or substantial in-stream restoration potential.

Analysts should use these indicators carefully. Because interrelationships among channel condition indicators are complex and poorly understood in many settings, it is usually prudent to use several indicators to obtain a more thorough representation of geomorphic conditions. Focusing on just one or two channel characteristics might not provide the degree of discrimination needed for the indicator to be useful as an assessment and monitoring tool. In addition, analysts should avoid drawing premature conclusions concerning watershed process interactions and associated problems based solely on application of stream classification methodologies (Kondolf, 1995; Miller and Ritter, 1996). In-stream or channel indicators do not provide an adequate substitute for hillslope sediment source analysis (Reid and Dunne, 1996). However, the converse is also true: hillslope indicators do not provide an adequate substitute for in-stream measures. Hillslope and in-stream indicators should be used to complement each other in most settings.

Biological and habitat indicators

Biological metrics often provide discriminating indicators for sediment TMDLs associated with impairment of the aquatic habitat use. Because the presence, diversity, and productivity of aquatic organisms of concern can be used to infer the habitat suitability characteristics, biological indicators can complement physical and chemical indicators in many TMDLs. Biological indicators can be used to detect the effects of changes in key habitat characteristics (e.g., aggradation, degradation, changes in channel diversity) on aquatic species.

Although it is possible to use bacteria and plant-related indicators of aquatic habitat quality, this discussion focuses on invertebrate- and fish-related indicators because they are most likely to be of use in establishing sediment TMDLs. Two general types of biological assessment tools are available. First, a wide variety of approaches focus on quantitative analysis of species numbers, diversity, and productivity. For more detailed guidance on biological indicator options and the selection of specific indicators, see USEPA (1989) and Platts et al. (1983). Second, several more qualitative or quasi-quantitative methods have been developed that integrate assessment of biological indicators with physical indicators (chiefly channel condition factors) and chemical indicators (e.g., temperature range) to yield composite habitat quality indicators. These methods include habitat typing (California Department

Table 4-5. Advantages and disadvantages of other channel condition indicators.

Advantages	Disadvantages
• Intuitive appeal to the public (people can see the effect in many circumstances). • Suspended sediment/turbidity impacts are primarily responsible for many designated use impacts. • Because sediment indicator data can also be used to estimate sediment loads (e.g., through use of rating curve methods), the indicator can serve "double duty." • Substantial experience as indicator of sediment problems from crop agriculture, urban runoff, and grazing. • Extensive data are available in some watersheds (especially for suspended sediment).	• Difficulty in associating changes in TSS/turbidity with specific management activities. • Large expected variation in time and space as function of precipitation, hydrograph, and other factors. • Can be difficult or unsafe to measure during high flows. • Difficulty in associating with some designated or existing use issues and establishing target conditions (e.g., habitat quality). • A focus on suspended sediment might not address larger particle sizes that move as bedload. • Bedload is difficult to measure accurately. • Streamflow or discharge usually needs to be measured at the same time for the data to be useful. • Difficult to distinguish human-caused changes.

of Fish and Game, 1994), assessment of proper functioning condition (USDOI-BLM, 1993/1995), and assessment of channel stability (Ohlander, 1991). Other methods of this type are reviewed in Dissmeyer (1994). Table 4-6 summarizes advantages and disadvantages of biological indicators for TMDL development.

Recommendations: Biological indicators should be considered for inclusion in sediment TMDL projects in many settings. For example, fish indicators often complement other TMDL indicators. However, because numbers of fish are often influenced by factors beyond sediment-related impacts, analysts should use caution in selecting a fish-related indicator as the sole TMDL indicator. In many settings, it is possible to design fish-related indicators to help control for confounding variables beyond sediment impacts. For example, the indicator of trout redd counts per stream mile was applied in the Ninemile Creek, Montana, TMDL by establishing target levels based on conditions in a neighboring, good-quality stream.

Invertebrate indicators have several characteristics that might make them preferable to fish indicators. They are relatively abundant in many settings, are good representatives of overall aquatic habitat condition, and are relatively sensitive to changes in sedimentation. The chief disadvantages of invertebrates include the relatively high level of expertise needed to analyze samples, the difficulty in collecting reliable samples, the need to measure them at the same time of year as the flow, and the difficulty of setting target conditions. In addition, the temporal and spatial variability of invertebrate populations can be very high. In temperate areas there is a strong seasonal variation in benthic macroinvertebrate biomass, diversity, and composition, and this variation must be considered when evaluating the use of invertebrates as indicators (Rosenberg and Resh, 1993). Additionally, benthic macroinvertebrate populations are often very sensitive to changes in substrate or other habitat characteristics, and this can make it very hard to compare samples from different streams or waterbodies. Local validation of invertebrate monitoring methods is necessary to develop meaningful target conditions over time or to compare conditions in reference streams and the study area. Analysts should

TMDLs Where Too *Little* Sediment Is Present

In some settings, such as the Trinity River in California, fish habitat impairment is associated with diminished sediment supply and altered hydrologic regimes due to main stem dam construction. In this type of setting, sediment supply shortages might result in channel bottom scour and erosion of spawning gravels. For TMDLs in scour settings, a different set of geomorphic and biological indicators might be needed to assess the degree of habitat impact and prospective solutions (e.g., management of dam releases and gravel replenishment).

Settings Where Biological Indicators Are Appropriate for TMDL Development

- Aquatic habitat uses are key concerns.
- Sufficient information is known about life histories and use of habitat.
- Quantitative methods have been locally tested and validated.
- Field personnel are trained in these methods and available for follow-up monitoring.
- Cause-effect relationships between sediment sources and in-stream habitat impacts are poorly understood.

Table 4-6. Advantages and disadvantages of biological assessment indicators

Advantages	Disadvantages
• Are often sensitive to the additive effects of multiple changes in hydrologic and erosion processes active in a watershed, including the effects of sediment discharges from multiple sources over time. • Can reflect the recovery of aquatic habitats from past land disturbances and associated sediment inputs and can account for the effects of sediments stored in waterbody channels after discharge. • Can be effective even if monitored rarely (e.g., annually or during key life stage periods only). • Provide direct measures of the designated or existing uses of concern in many projects and consequently have significant public appeal (especially fish counts).	• Qualitative methods might not yield results that can be reliably used for TMDL numeric targets. • Often difficult to replicate results of qualitative assessment methods. • Not very useful for distinguishing between stressors of concern (e.g., sediments, nutrients, temperature). • Some methods are difficult to use and/or quantify (e.g., fish are difficult to count accurately). • In many settings, so few fish are present that fish- related indicators cannot be reliably used. • Fish indicators are very sensitive to confounding influences (e.g., effects of fishing within the watershed or in the ocean, in the case of anadromous fish; habitat stressors other than sediment [temperature]). • Because many fish populations have been severely affected for substantial periods of time, it is difficult to set appropriate target conditions for fish counts.

not assume that invertebrate indicators are always good indicators of salmonid habitat conditions. Although evaluations of invertebrate and fish measurements in eastern streams have found good correlations, some researchers in the Pacific Northwest have expressed concern that invertebrate measurements provide poor indicators of western salmonid habitat quality.

Qualitative and quasi-quantitative indicators (e.g., Ohlander, 1991; USDOI-BLM, 1993/1995) can greatly assist in defining sediment problems and near-stream sources. However, they might not prove viable as TMDL indicators because results are often imprecise, difficult to replicate, difficult to compare with target levels, and not fully validated as designated use assessment methods. Analysts should use caution in applying such methods to derive TMDL numeric targets for these reasons.

Riparian/hillslope indicators

Not all TMDL indicators must focus on the waterbody. In many cases, it is difficult to analyze the relationship between upslope sources of sediment and in-stream impacts of sediment discharges. The hillslope-in-stream connection is particularly difficult to evaluate in many western coastal watersheds. Often these are highly erosive, steep watersheds that are subject to extreme variations in sediment-producing runoff events and in which anadromous fisheries are the principal concern.

Riparian and hillslope indicators provide additional indicators of environmental conditions associated with designated or existing use protection; however, they should be used to complement in-stream indicators and not as substitutes for in-stream indicators. Riparian and hillslope indicators would not suffice as lone TMDL numeric targets because they do not provide a direct interpretation of water quality standards, which focus on in-stream uses. See the Redwood Creek TMDL case study for an example application of both in-stream and hillslope indicators.

TMDLs Using Riparian/ Hillslope Indicators

Deep Creek, MT (bank stability)
Redwood Creek, CA
South Fork Trinity River, CA
San Diego Creek, CA

Riparian or upslope indicators represent a wide range of influences on stream sediment quality:

- Riparian buffer width sizes and riparian vegetation character.
- Amount of large woody debris present (e.g., number or volume of wood pieces per mile).
- Disturbance indices such as Equivalent Roaded Acreage (USDA Forest Service, 1988).
- Erosion hazard indices.
- Percent impervious land within zone adjacent to a waterbody.
- Landslide area.

Depending on the context in which they are included in a TMDL, riparian and hillslope indicators suitable for TMDL numeric targets might not include actions, BMPs, land management policies, or projects to be implemented to address riparian or hillslope sediment issues. Such actions, practices, and projects do not identify desired conditions; rather, they identify means to accomplishing environmental objectives. In some cases, the use of hillslope indicators will be related to BMPs, such as when the hillslope indicator is related to road crossing culvert sizes. It might be feasible in limited circumstances to include such actions, practices, and projects as part of the allocation process designed to identify methods for attaining needed changes in sediment processes. To help clarify the differences between hillslope targets, allocations, and implementation measures, Table 4-7 provides two example applications. Advantages and disadvantages of riparian and hillslope indicators are summarized in Table 4-8.

Settings Where Riparian/Hillslope Indicators Are Appropriate

- Bank erosion is a key sediment source.
- Grazing, recreation, or waterside development are key issues.
- Woody debris is responsible for channel diversity and pool formation.
- Upslope/in-stream linkages are difficult to evaluate.
- Extensive prior monitoring of these indicators has been conducted.
- Riparian area land management options are likely to be key components of the TMDL implementation plans.

Recommendations: Upslope and riparian indicators can prove useful in many TMDLs, especially in settings where in-stream or stream channel indicators are particularly difficult to associate with sediment sources. Inclusion of hillslope and riparian indicators in the suite of indicators is recommended because they highlight sediment problems before they happen and because there is often a long lag time between hillslope disturbance and downstream sediment impacts. Although this class of indicators can often be effective in improving stream condition, they can be difficult to apply in settings where establishing target conditions is problematic.

Comparisons of indicator candidates

Although selection of indicators is necessarily a site-specific decision, Figure 4-2 offers some guidance on selecting indicators that might be most appropriate for different types of waterbodies and different designated uses.

In general, the larger the TMDL study area, the more likely it will be that indicators will need to be monitored and target conditions established in multiple locations. This is particularly true in settings where indicators measured toward the bottom of the watershed are incapable of detecting key designated use changes in critical areas (e.g., upstream spawning areas) or of establishing linkage with the source analysis and control elements of the TMDL. Therefore, in larger study units (e.g., > 50 mi^2), the selection of indicators may be influenced by the availability of future resources for monitoring. Table 4-9 provides insights into addressing indicator selection issues in large watersheds.

Tables 4-10 through 4-13 provide additional summary comparisons of the candidate indicators. Table 4-10 reviews the sensitivity of indicators to key designated or existing uses. Table 4-11 reviews the sensitivity of indicators to primary sediment source management activities. Table 4-12 compares candidate indicators with respect to several key indicator evaluation criteria. In addition to the indicator's sensitivity to designated uses and sediment sources, key criteria include practicality (relative ease of using the indicator), cost to collect and interpret information, track record (degree of productive experience using this indicator), public understanding, and knowledge of reference conditions (whether reference condition values are available from comparable studies or literature sources). Table 4-13 considers the relative utility of available indicators with respect to hydrologic, geomorphic, geologic, topographic, and soil considerations. Indicator selection requires careful consideration of the unique mix of issues, opportunities, and characteristics present in each watershed. Analysts are encouraged to use this information as the starting point in an iterative process and to consult key references and local experts in the final selection of indicators.

Table 4-7. Examples of in-stream and hillslope targets, allocations, and implementation measures

Indicators/ Targets	Allocations	Implementation Measures
Instream: • Median particle size >12 mm • <15% fines <0.85 mm Hillslope: • Attain < 3 miles roads with erosion potential per mi^2 study area	Landowner 1: • Reduce erosion-prone road mileage by 12 miles Landowner 2: • Reduce erosion-prone road mileage by 5 miles	Landowner 1: • No new roads • Retire 5 miles of existing road Landowner 2: • Retire 2 miles of existing road • Retrofit 15 stream crossings
Instream: • V* < 0.2 • >50 redds per mile Hillslope: • Attain < 10% actively eroding streambanks	Reduce length of eroding banks by Tributary 1: 25% Tributary 2: 5% Tributary 3: 10%	Tributary 1: stream and bank restoration project Tributary 2: new riparian plantings and installation of stock watering tanks Tributary 3: new riparian fencing

4. What are appropriate target values for the chosen indicators?

For each numeric indicator used in a TMDL, a desired or target condition needs to be established to provide measurable goals and a clear linkage to water quality standards attainment. Target values for some indicators might already have been established through state water quality standards (e.g., for turbidity). This is usually not the case for indicators used in sediment TMDL development. There are a variety of additional mechanisms to determine appropriate target values. All of the methods for setting target values require an interpretation of what constitutes impaired versus unimpaired conditions. In many cases this determination is subjective (e.g., what level of fish habitat quality or water clarity is equated to "full support" of designated uses?). Regardless of the method used to establish the indicator values, it is important to solicit input from as many stakeholders as possible, including the public and regulatory agencies. Stakeholder input is an important component of the Watershed Approach (USEPA, 1996b), and it can be particularly useful for interpreting narrative standards. For example, in a stream designated for support of a

Table 4-8. Advantages and disadvantages of riparian and hillslope indicators

Advantages	Disadvantages
• Directly address key sources of concern (e.g., streambanks, roads, or timber harvest areas). • Address key mitigating factors that may limit sediment delivery to streams (e.g., riparian buffers). • Facilitate goal setting for large woody debris recruitment, a key factor in the maintenance of healthy stream conditions in many watershed types. • Build connections with source analysis, which are critical to TMDL development. • Relatively easy to understand and measure (e.g., buffer width). • Help address difficulty of linking sources to in-stream impacts by providing intermediate indicators. • Usually do not have to be measured more than annually to yield useful information.	• Quantitative indicators of this type (e.g., woody debris and bank stability) have not been widely demonstrated or applied. • Setting desired conditions for these indicators would be difficult because some are not widely used as quantitative indicators. • The linkage of upslope and riparian indicators to in-stream designated or existing use conditions has not been clearly established in most of the country (e.g., disturbance indicators). • Some of these indicators (e.g., bank stability and woody debris) are relatively difficult and time-consuming to measure, although they might not need to be measured often.

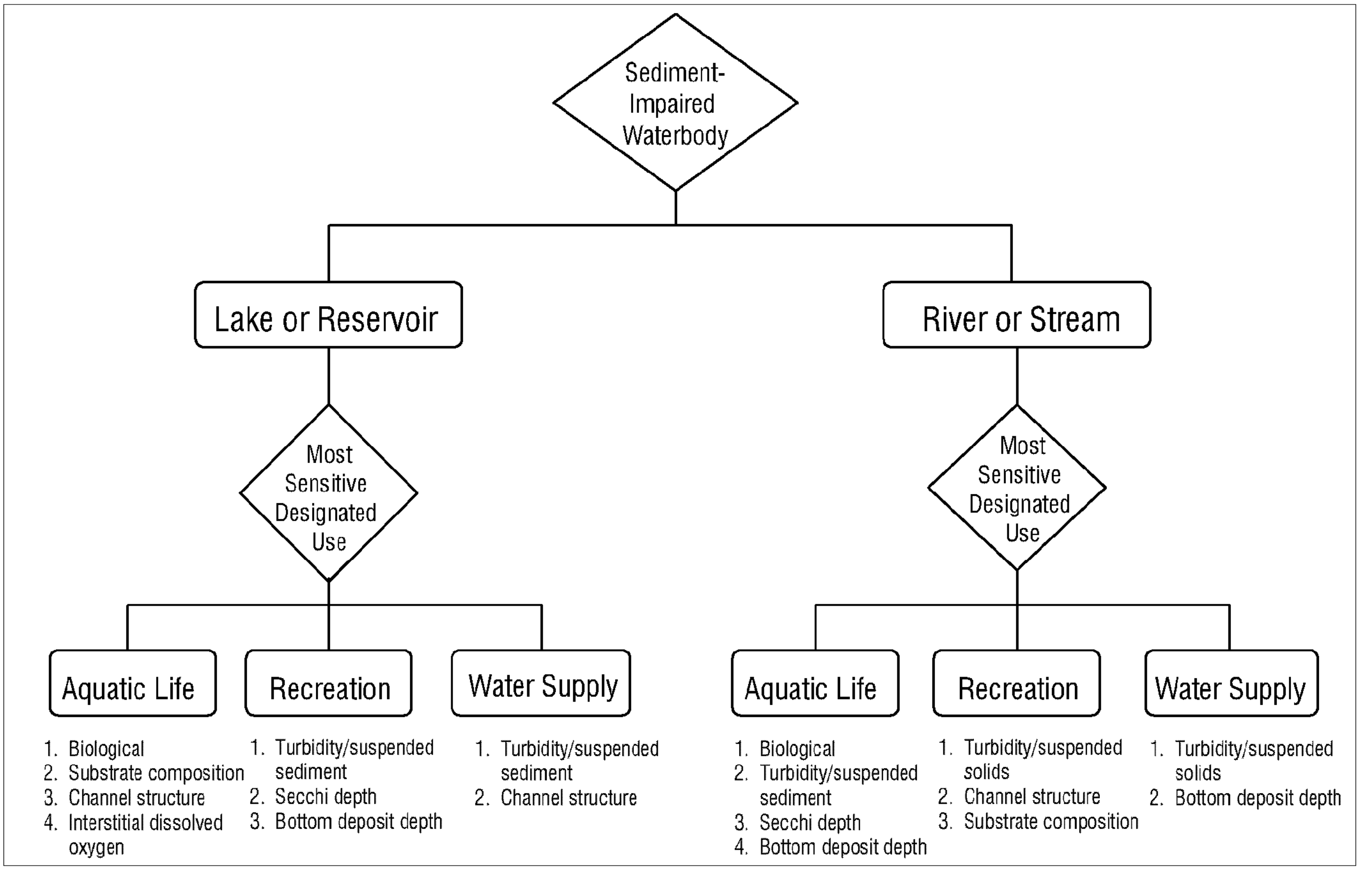


Figure 4-2. Guidelines for selecting indicators based on waterbody type and several designated uses.

cold water fishery, a biological indicator aimed at assessing the health and diversity of the fish population could be refined into a quantitative target based on stakeholder consensus as to what constitutes a sufficiently viable fishery.

Factors for establishing target conditions

Degree of experience applying the indicator(s) in the area or in similar settings

Where local experience has been gained in applying sediment indicators, it is often possible to identify target conditions through analysis of historical conditions or reference stream conditions in relatively high quality parts of the watershed. Where less local or directly analogous experience is available, it is appropriate to establish more conservative targets.

Variability of conditions in the watershed

The larger the study area for the TMDL and the more heterogeneous the waterbody characteristics in the watershed, the more important it will be to consider establishing multiple target conditions for the TMDL. It might be useful to stratify the targets based on spatial distinctions (e.g., key habitat areas vs. nonhabitat areas, main stems vs. tributaries, or aggrading vs. degrading reaches). Similarly, it might be necessary to account for seasonal and interannual variations in setting target conditions.

Margin of safety considerations

Determination of the margin of safety in the establishment of target conditions should consider provisions for monitoring and adaptive management. Factors that should be considered in defining the margin of safety include the expected accuracy or reliability of the indicator for the local designated use and the degree to which designated uses are rare or valuable.

Table 4-9. Considerations in selecting indicator(s) for large watersheds

Resources Available for Future Monitoring	Present or Future Resources Available to Develop TMDL		
	Low	**Medium**	**High**
None	Biological indicator with very high margin of safety (MOS)	Sediment or biological indicator with analysis linkage to BMPs and high MOS	Allocate resources for future monitoring and do less complex TMDL analysis
Low	Single sediment, substrate, or biological indicator with high MOS and annual monitoring	Sediment or substrate indicator + biological or upland indicator with analysis linkage to BMPs, moderate MOS, and annual monitoring	At least two indicators (per medium), extensive analysis of control/restoration effectiveness, moderate MOS, and annual monitoring. Multiple "target" points possible.
Medium	Sediment or substrate indicator + biological or upland indicator with high MOS and more frequent monitoring	Sediment or channel indicator(substrate or other) + biological or upland indicator with analysis linkage to BMPs, moderate MOS and more frequent monitoring. Multiple "target" points possible.	At least two indicators (per medium), extensive analysis of control/ restoration effectiveness, moderate MOS and more frequent monitoring. Multiple "target" points possible. Watershed model as analytical tool.
High	Sediment or substrate indicator + biological or upland indicator with high MOS and frequent monitoring. Multiple "target" points probable.	Multiple indicators appropriate, including channel and biological metrics in multiple locations. Moderate to low MOS and frequent monitoring. Multiple "target" points probable. Watershed model as analytical tool.	Multiple indicators appropriate, including channel and biological metrics in multiple locations. Robust analysis of linkage to BMPs. Low MOS and frequent monitoring. Multiple "target" points appropriate. Watershed model as analytical tool.

Water quality standards

Several states have adopted numeric criteria for suspended sediment concentrations or turbidity that can be used as targets if the indicators are relevant to the TMDL. Usually, these standards are set as either absolute thresholds (e.g., turbidity no greater than 25 NTU) or relative targets (e.g., no turbidity increases greater than 10 percent or 5 NTU above background conditions). These standards are not always easy to apply given the spatial and temporal variability of suspended sediment and turbidity, but they are related to designated use concerns and often provide a ready basis for making the required TMDL linkage to attainment of water quality standards.

Information Sources for Determining Indicator Target Values

Water quality standards
Reference sites
Literature values
User surveys
Functional equivalents
Best professional judgment

Comparison to reference sites

One method for establishing target values is comparison to reference sites—waterbodies that are representative of the characteristics of the region and subject to minimal human disturbance. Where narrative standards are involved, assessing environmental conditions in receiving waters often depends on comparing observed conditions to expected conditions. This comparison is typically done by comparing data collected from impaired sites to similar data from the same sites collected before impairment and/or from one or more appropriate reference sites where designated uses are in good condition. Conditions at the reference site (e.g., suspended sediment concentrations) can then be interpreted as approximate targets for the indicators at the impaired site. A disadvantage to this approach is that it might not aid in determining an impairment threshold. Reference sites may represent the completely unaffected state, a relatively unaffected state, or increasing degrees of existing impact.

Table 4-10. Sensitivity of indicators to designated uses

Indicator	Designated Uses					
	Domestic Water Supply	Agricultural Water Supply	Hydroelectric Reservoir Storage	Recreation	Cold-Water Habitat	Warm-Water Habitat
SEDIMENT						
Suspended	1	1-2	1	1-2	1-2	1-2
Turbidity	1	2	2	1-2	2-3	1-2
<u>CHANNEL CHARACTERISTICS</u>						
Bed Material Size	3	4	4	3	1-2	1-2
<u>GEOMORPHOLOGY MEASURES</u>						
Width/Depth Ratio	4	4	4	2-3	1-2	2-3
Cross Sections	4	4	4	2-3	1-2	2-3
Bank Stability	3	4	4	1-2	1-2	1-2
Pool Measures	4	4	4	2-3	1-2	1-2
WOODY DEBRIS	4	4	4	2	1	1
<u>BIOLOGICAL INDICATORS</u>						
Invertebrates	3-4	3-4	4	3	1	1
Fish Counts	4	4	4	1	1	1

KEY: 1 Use highly sensitive to indicator in most cases
2 Use closely related and somewhat sensitive in most cases
3 Use indirectly related and not very sensitive
4 Use largely unrelated to indicator

Source: MacDonald et al., 1991

Table 4-11. Sensitivity of indicators to sediment sources

Indicator	Potential Sediment Sources							
	Roads	Timber Harvest	Grazing	Crop Agriculture	Urban Runoff	Construction	Sand and Gravel/ Placer Mining	Handlock Mining
<u>SEDIMENT</u>								
Suspended	1-2	2-3	1-3	1-2	1-3	1	1	3
Turbidity	1-2	2-3	1-3	1-2	1-2	1	1	3
<u>CHANNEL CHARACTERISTICS</u>								
Bed Material Size	1	1-2	2-3	1-3	2-4	1-3	1	3-4
Embeddedness	1-3	1-3	2-3	2-3	2-4	1-3	1-3	3-4
<u>GEOMORPHOLOGY MEASURES</u>								
Width-Depth Ratios	2-3	2-3	1-2	2	1-3	1-3	1-2	3-4
Cross Sections	2-3	2-3	1-2	2	1-3	1-3	1-2	2-4
Bank Stability	2-3	1-2	1	1-2	1-3	2-3	2-3	2-4
Pool Measures	1-2	1-3	2	1-2	1-3	1-2	1-2	2-4
WOODY DEBRIS	3-4	1	3-4	3-4	2-3	4	3	3-4
<u>BIOLOGICAL INDICATORS</u>								
Invertebrates	1	1	2	1	1	1	1-2	1
Fish Counts	1	2	2	1-3	1-2	1-2	2-3	1

KEY: 1 Directly affected and highly sensitive
2 Use closely related and somewhat sensitive
3 Use indirectly related and not very sensitive
4 Largely unaffected and insensitive

Source: MacDonald et al., 1991

Table 4-12. Comparison of sediment-related indicators for TMDL development

Indicator	Practicality	Cost	Track Record	Public Understanding	Knowledge of Reference Conditions	Comments
SEDIMENT						
Suspended	M-L	H-M	G-F	G-F	G-F	2,3
Turbidity	H-M	M	G-F	G	G-F	2
CHANNEL CHARACTERISTICS						
Bed Material Size	H	L	G	F	G-F	1
Embeddedness	H	L	F	F	F-P	1
GEOMORPHOLOGY MEASURES						
Width/Depth Ratio	M	L-M	F	F-P	G-F	
Cross Sections	M	L-M	G-F	F	G-P	
Bank Stability	M-L	M	F	G	F-P	
Pool Measures	H-M	L-M	G	G-F	F	1
WOODY DEBRIS	M-L	M	F	G	F	
BIOLOGICAL INDICATORS						
Invertebrates	M	M-H	G-F	G-F	F	
Fish	M	M-H	G-F	G	F	3

KEY:
- H High
- M Medium
- L Low
- G Good
- F Fair
- P Poor
- 1 Best for fish designated or existing use
- 2 Best for water supply
- 3 Monitoring difficult

Table 4-13. Utility of sediment-related indicators for different environmental settings

	Environmental Setting									
	Geology					Topography			Soils	
Indicator	Granitics	Basalts	Sedimentary	Marine	Glacial	Low Slope	Steep	Over Steep	More Clays	More Sandy
SEDIMENT										
Suspended	2	2	2	2	1-2	2	1-2	2-3	2	2
Turbidity	2-3	2-3	1-2	2-3	2-2	2	1-2	2-3	1	2-3
CHANNEL CHARACTERISTICS										
Bed Material Size	1	1-2	1-2	1-2	2	2	1-2	1-2	1-2	2-3
Embeddedness	1	2	2-3	2-3	2	2-3	1-2	1-2	2	1-2
Pool Measures	1	1-2	1-2	1-2	1-2	2-3	1	1		
GEOMORPHOLOGY MEASURES										
Channel Geometry	1-2	1-2	1-2	1-2	1-2	2-3	1-2	2	2	1-2
Bank Stability	2	2	2	2	2	1-2	1-2	1-2	2	2
WOODY DEBRIS	1-2	1-2	1-2	1-2	1-2	2-3	1-2	1-2	2-3	2-3
BIOLOGICAL INDICATORS										
Invertebrates	2	2	2	1-2	2	1-2	1-2	1-2	2	2
Fish	1-2	2	2	1-2	2	2-3	2	2	2-3	2

KEY:
1 Clearly useful; extensive record demonstrating sensitivity in this setting
2 Sometimes useful; limited or mixed record of use in this setting
3 Probably not very useful; no or poor record of use in this setting

Table 4-13. Utility of sediment-related indicators for different environmental settings (continued)

Indicator	Environmental Setting					
	Hydrology				Geomorphology	
	Perennial Flow	Intermittent/ Ephem. Flow	Dom. by Major Events	Dom. by Frequent Events	Sandy Bottom	Gravel/Cobble
SEDIMENT						
Suspended	1-2	2-3	3	1-2	1-2	2-3
Turbidity	1-2	2-3	3	1-2	1-2	2-3
CHANNEL CHARACTERISTICS						
Bed Material Size	1-2	2	1-2	2	3	1
Embeddedness	2	2-3	2	2	3	1-2
Pool Measures	1-2	2	1-2	2	2-3	1-2
GEOMORPHOLOGY MEASURES						
Channel Geometry	2	2	1-2	1-2	2	1-2
Bank Stability	2	2	2	1-2	1-2	2
WOODY DEBRIS	1-2	2-3	2	2-3	2-3	1-2
BIOLOGICAL INDICATORS						
Invertebrates	1	1-2	1-2	1-2	2	1-2
Fish	1-2	2-3	2	2	2	1-2

KEY:
1 Clearly useful; extensive record demonstrating sensitivity in this setting
2 Sometimes useful; limited or mixed record of use in this setting
3 Probably not very useful; no or poor record of use in this setting

Selection of an appropriate reference site should reflect a clear understanding of the overall system. The reference sites may be within the study watershed or in nearby or even distant watersheds, and they should be selected based on careful comparison of key watershed characteristics and processes (e.g., geology, soils, topography, land use). In general, though, the most useful reference sites are located within the watershed, relatively near the point where impact is expected. Reference sites may be difficult to find.

User surveys

Several states have used user surveys to determine indicator target values, especially in lakes and reservoirs. This approach is especially useful when the designated use of the waterbody is recreational. Waterbody users can be questioned concerning their perceptions of water quality conditions and the quality of the recreational experience. Survey results can be correlated with simultaneous water quality measurements to establish target values at the border between acceptable and unacceptable conditions. For example, if 50 percent of those surveyed agree that their aesthetic enjoyment of a lake is impaired when water clarity diminishes to less than 40 feet (measured with a Secchi disk), this value could represent a possible clarity (Secchi disk) target value. The survey approach recognizes that such an assessment of the overall water quality of a waterbody is highly subjective and can vary considerably by region.

Literature Values

Several TMDLs have included numeric targets based on information from research studies of the relationship between the selected sediment indicator(s) and the beneficial use of concern. For example, the Garcia River, California, TMDL included numeric targets for fine sediments based on reviews of several research publications that evaluated the fine sediment levels at which salmonid survival began to diminish.

Indicator relationships

In some cases, information is available to identify target conditions for indicators that are functionally related to the indicators selected for TMDL analysis. For example, in the Silver Creek, Arizona, demonstration TMDL, suspended sediment was the indicator of choice for the TMDL because of its usefulness in developing sediment budgets and the availability of data. Using available turbidity and suspended sediment data for Silver Creek, the relationship between turbidity and suspended sediments was evaluated through regression analysis. Because a close linear relationship was observed, the TMDL target for suspended sediment was determined as a watershed-specific function of the turbidity.

Best professional judgment

It is sometimes infeasible to develop numeric targets based on the methods described above because adequate information is not available or relationships between designated uses and selected indicators are not well understood. In this case, it may be feasible to develop target values based on the best professional judgment of resource professionals involved in TMDL development. To ensure that these targets are defensible, analysts are advised to

- Consult with multiple experts with local experience rather than relying on a single opinion.
- Thoroughly document the thinking underlying the target, including assumptions, related experience, or other factors considered in identifying the targets.
- Remember that targets must be set at levels that are believed to result in full support of the impaired designated uses (i.e., water quality "improvements" might be inadequate).
- Design the TMDL as a phased TMDL that includes a monitoring plan to assess whether the numeric targets are appropriate for the particular situation.

Methods for expressing numeric targets

The dynamic interactions between the multiple watershed processes that affect sediment delivery and impacts in many streams may make it difficult to establish individual target conditions. In general, sedimentation problem solving is more likely to succeed if it strives to mimic the natural ranges of watershed process behaviors, including extreme events, which cause adverse sediment impacts on designated uses (Bisson et al., 1997). In many watersheds it is reasonable to expect substantial spatial and temporal variability in sediment indicators. Where this is the case, it might be appropriate to express target conditions for the watershed to account for expected variability in key watershed processes yet still provide measurable goals for restoration and protection of designated or existing uses over time.

There may be resistance to developing "hard" targets if it is perceived that they will limit land management flexibility without having an adequately robust analytical basis. Careful design of targets will help ensure that the results are not perceived as arbitrary; however, significant uncertainty regarding the precision of the targets may exist in the best of circumstances. In such circumstances, it might be appropriate to frame the numeric indicators and associated target conditions as testable hypotheses that will be reviewed and revised as necessary over time. The TMDL process provides for the inclusion of adequate margins of safety to account for such uncertainties. If management flexibility is reduced through the application of numeric targets, there may be some incentives to conduct follow-up monitoring and review to determine if targets are appropriate or if they should be revised based on new information.

In addition, it might make sense to establish both interim and final numeric targets for the TMDL. The interim targets may represent target levels believed to be reasonably attainable in relatively short periods of time. The final targets are set at levels at which designated uses are protected and the actual desired condition for the resource is represented. Under no circumstances do interim targets replace final targets set at levels necessary to attain water quality standards. Using both interim and final targets is particularly well suited to situations in which

- It might take many years to attain final targets and water quality standards because of the slow response of waterbodies to land use changes.
- Analysts and stakeholders want clearer short-term measures to guide near-term implementation and evaluate TMDL effectiveness (i.e., are we on the right track?).
- The analytical basis for final target levels is weak.

Table 4-14 summarizes several possible approaches to establishing numeric target levels for TMDLs. In general, the objective in establishing target conditions is to articulate the condition(s) for the TMDL indicators that represents fully supported designated or existing uses. Analysts should be creative in establishing ways to achieve this objective while ensuring that the TMDL approach is based on sound scientific principles.

Analysts developing targets for TMDLs for large watershed areas should consider the potential need for different targets for different areas or time frames. To develop targets that address large study areas, several approaches are available:

- Different target values can be established for multiple measurement points (e.g., key habitat areas, mouths of several tributaries, or areas where land uses change).
- A different target may be set at a key watershed outlet, critically vulnerable or sensitive area, or other representative waterbody area.
- A range of values can be applied in the study area.

5. How do the existing values compare to the target values?

The last step in establishing numeric targets is to compare existing and target conditions for indicators selected for the TMDL. This key step should not be overlooked because it provides critical information that can be used to evaluate whether watershed management and restoration actions are likely to be effective in attaining water quality standards. Although the comparison might appear easy to make, in practice some indicators are not as amenable to comparison as others. The best approach to making comparisons is influenced by the types of indicators selected, the approach to articulating the target condition(s) for each indicator, the spatial and temporal scales selected for the TMDL, and the methods used to link numeric targets to other TMDL elements. This section briefly reviews factors to consider in making condition comparisons and discusses some methods for making reasonable comparisons.

Key factors to consider in comparing numeric targets with existing conditions

Variability in conditions within study area

If existing conditions for the selected indicators vary substantially within the study area or at different times of the year, the comparison method should be able to account for spatial or temporal differences.

Table 4-14. Methods for expressing numeric targets for TMDLs

Method	Example Application
Absolute values or thresholds	• No more than 15% fine sediment > 0.85 mm in riffles (Garcia River, CA) • No net increase in sediment discharge above background (Mattole River, CA) • Depth of key refuge area no less than 6 feet deep (Newport Bay, CA)
Conditional values	• Maximum 10% increased turbidity when background >50 NTU (AZ WQS) • 20% long-term reduction in average annual in-stream load compared to 1995 value (Deep Creek, MT)
Functional values	• Suspended sediment load as function of flow (target is slope of TSS-flow regression equation) (Deep Creek, MT)
Relative values	• Average turbidity no greater than that measured simultaneously at paired reference stream (Caspar Creek, CA)
Ranges of values	• 1,000-3,000 annual returning spawning chinook salmon
Index values	• Biological indicator index no greater than state index of biological integrity level for "full use support" (Waimanalo Stream, HI [draft]) • Acreages of aquatic habitat of different types in wildlife refuge (Newport Bay, CA)

Level of accuracy needed in the condition comparison

Analysts should consider how the comparison will be used to support the TMDL. In TMDL projects where source reductions will be determined by comparing existing and target conditions, it might be more important to make relatively accurate comparisons. However, in cases where source allocations are based partly or completely on other factors, the comparison could be relatively rough.

Theoretical basis for change in the indicator

Analysts should understand how changes in the selected indicators are expected to occur in the study area (i.e., what are the driving forces of change in the watershed and how do these forces manifest themselves in the selected indicators?).

Methods for comparing existing and target conditions

Direct comparison of data for existing and target levels for indicators selected for the TMDL provides the most straightforward method for estimating sediment reductions needed to attain water quality standards. However, the analyst should be careful in making such comparisons, particularly if there is a strong analytical basis for assuming a nonlinear pattern of change over time in the indicators. Statistical analysis tools (especially regression analysis) are particularly useful for comparing existing and target conditions in many settings. (See USEPA, 1997b, for additional information on regression analysis for nonpoint source assessment.)

In addition, averaging existing conditions for indicator values across the entire study area is inappropriate in many settings because this practice can obscure important differences in individual locations and make it more difficult to identify source-to-in-stream impact relationships. Table 4-15 presents a summary of approaches for comparing existing and target conditions. Note that these methods are not mutually exclusive.

In cases where the analytical uncertainty precludes direct comparisons of existing and target conditions, other approaches are more prudent. For example, a TMDL could discuss the percentage of land area or stream miles exceeding a TMDL indicator target level rather than directly discussing the magnitude of the exceedance. However, it is often useful to describe the estimated magnitude of the problem to facilitate development of allocations.

6. What changes does the proposed rule speak to?

On August 23, 1999, EPA published proposed rules that specify that approvable TMDLs must include at a minimum ten elements. Within the water quality indicators and target values step, an approvable TMDL will need to include the following information:

1. Identification of the pollutant for which the TMDL is being established and quantification of the maximum pollutant load that may be present in the waterbody and still ensure attainment and maintenance of water quality standards; and

Table 4-15. Methods for comparing existing and target conditions for numeric targets

Methods and Rationale	Examples
Direct comparison of loads: Best where load estimates and targets are reliable	Existing (10 tons/year) - target (5 tons/year) = 5 ton/year needed reduction
Percent reduction comparisons: Best where absolute load estimates are rough or non-load-based indicators are used	Existing (~10 tons/year) - target (~5 tons/year) = ~ 50% needed reduction
Factor comparisons: Best where relationship between indicators and sources is not well established	Existing turbidity levels (75-125 NTU); target level (50 NTU); therefore, existing levels exceed target level by about a factor of 2
Indirect comparisons: Best where indicator changes in response to driving forces that are nonlinear or poorly understood	Existing bioassessment index level = 30; target = 75. Comparison indicates waterbody is severely impaired but provides no basis for estimating needed sediment load reductions

2. Identification of the amount or degree by which the current pollutant load in the waterbody deviates from the pollutant load needed to attain or maintain water quality standards.

RECOMMENDATIONS FOR IDENTIFICATION OF WATER QUALITY INDICATORS AND TARGET VALUES

- If available, the numeric standard established in water quality standards should be used as the TMDL indicator and target value.
- Where no applicable numeric standard exists, establish a target value through a combination of literature values, reference waterbodies, additional monitoring, stakeholder input, and the narrative water quality standard. Document all assumptions made in establishing the target.
- The chosen indicator should be sensitive to geographic and temporal influences.
- Consider how many indicators are needed; single indicators are appropriate for some situations (e.g., turbidity threshold for drinking water source), but some watersheds might require the use of multiple indicators to account for complex processes or a lack of certainty regarding individual indicator effectiveness.

RECOMMENDED READING

(Note that the full list of references for this chapter is included at the end of the document.)

Chapman, D.W., and K.P. McLeod. 1987. *Development of criteria for fine sediment in the Northern Rockies Ecoregion*. EPA 910/9-87-162. U.S. Environmental Protection Agency, Washington, DC.

MacDonald, L., A.W. Smart, and R.C. Wissmar. 1991. *Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska*. EPA 910/9-91-001. U.S. Environmental Protection Agency, Region 10, Nonpoint Source Section, Seattle, WA.

Peterson, N.P., A. Henry, and T.P. Quinn. 1992. *Assessment of cumulative effects on salmonid habitat: Some suggested parameters and target condition*. Prepared for the Washington Department of Natural Resources and The Coordinated Monitoring, Evaluation and Research Committee, Timber Fish and Wildlife Agreement. March 2.

Source Assessment

Objective: Characterize the types, magnitudes, and locations of sources of sediment loading to the waterbody.

Procedure: Compile an inventory of all sources of sediment to the waterbody. Sources may be identified through assessment of maps, data, and reports and/or field surveys. It is likely that a combination of techniques will be needed depending on the complexity of the source loading and watershed delivery processes. After an inventory has been compiled, monitoring, statistical analysis, modeling, or a combination of methods should be used to determine the relative magnitude of source loadings, focusing on the primary and controllable sources of sediment.

OVERVIEW

The source assessment is needed to evaluate the type, magnitude, timing, and location of loading of sediment to a waterbody. A number of factors can be considered in conducting the source assessment. These factors include identifying the various types of sources (e.g., point, nonpoint, background), the relative location and magnitude of loads from the sources, the transport mechanisms of concern (e.g., runoff vs. mass wasting), the routing of the sediment through the waterbody, and the time scale of loading to the waterbody (i.e., duration and frequency of sediment loading to receiving waters). Of particular concern is what loading processes cause the impairment of the waterbody of concern. The evaluation of loading is typically performed using a variety of tools, including existing monitoring information, aerial photography analysis, simple calculations, spreadsheet analysis using empirical methods, and a range of computer models. The selection of the appropriate method for determining loads is based on the complexity of the problem, the availability of resources, time constraints, the availability of monitoring data, and the management objectives under consideration. It is usually advantageous to select the simplest method that addresses the questions at hand, uses existing monitoring information, and is consistent with the available resources and time constraints for completing the TMDL.

This chapter describes different types of sources, identifies procedures for characterizing loadings, and introduces a process for tool selection for TMDL development. The source assessment process endorsed in this protocol relies on many of the principles associated with development of sediment budgets, as described in Reid and Dunne (1996).

A sediment budget is an "accounting of the sources and disposition of sediment as it travels from its point of origin to its eventual exit from a drainage basin" (Reid and Dunne, 1996). Sediment budget analyses are useful both for the conceptualization of sediment problems and as a tool for estimating sediment loadings. Full-scale sediment budgeting provides an inventory of the sources of sediment in a watershed and estimates sediment production and delivery rates from each source. Component processes are identified, and process rates are usually evaluated independently of one another. All of the relevant processes are quantified, including hillslope delivery processes (creep, mass movement), channel sources (e.g., bank collapse), in-channel storage, bedload and suspended sediment transport capacity, and net sediment yield from the basin (Figure 5-1). If the effects of particular land use activities on each process are known, the overall influence of a suite of existing or planned land use activities can be estimated. Sediment budgeting is particularly effective for evaluating nonequilibrium situations, where channel loads do not necessarily represent hillslope erosion rates. The time and resources needed to develop a full sediment budget will vary depending on the geographic scale and required degree of accuracy, but it should be possible to

Key Questions to Consider for Source Assessment

1. What sources contribute to the problem?
2. How should sediment sources be grouped?
3. What technical and practical factors affect selection of methods?
4. What is the appropriate source assessment method?
5. How do estimated source contributions compare with natural or background levels?
6. How can the source assessment be described for TMDL submittal?
7. What changes does the proposed rule speak to?

develop rough sediment budgets adequate for TMDL purposes (Reid and Dunne, 1996).

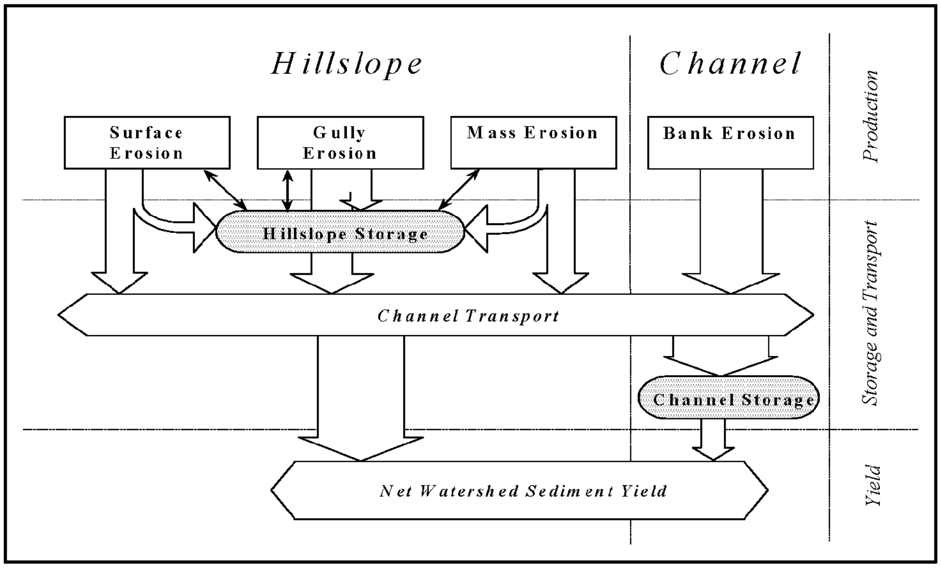


Figure 5-1. Sedimentation process

Analysts are encouraged to consider developing sediment budgets because they can be used to connect excess sediment load at a point of impact to sources of sediment generation and can thus be used to target load reductions. The analysis of sediment transport rates included in full sediment budgets is particularly helpful in evaluating how changes in stream structure (e.g., width-depth ratios) might respond to changes in sediment source management or restoration activities. Sediment budgets can usually be developed through (1) single models that estimate erosion for multiple source categories and assess in-stream processes and fate or (2) a combination of different source estimation and fate analysis methods for different sources or steps in sediment movement through the system (Reid and Dunne, 1996). It is important to note that detailed sediment budgets are not needed for all sediment TMDLs. For purposes of TMDL development, an estimation of the major sources of sediment might be adequate. This estimation can be done in several ways, ranging in complexity and intensity from interpretation of aerial photographs to on-the-ground surveys. Partial sediment budgets identify sediment sources and provide gross estimates of sediment delivery to waterbodies. This level of detail allows prioritization of erosion control efforts.

KEY QUESTIONS TO CONSIDER FOR SOURCE ASSESSMENT

1. What sources contribute to the problem?

The development of a TMDL includes the identification of the various sediment sources causing the impairment in the listed waterbody. Sediment sources typically fall into one of the following categories:

- Agriculture
- Silviculture (logged or burned areas)
- Rangeland
- Construction sites
- Roads
- Urban areas
- Landslide areas
- In-stream sources (e.g., stream or lake banks)

Sedimentation can be divided into the following discrete processes:

- Weathering and erosion (liberation of soil or rock particles from the soil or rock matrix).
- Hillslope delivery (movement of eroded material to the waterbody, minus upslope storage).
- In-stream transport (movement of sediment downstream in the waterbody).
- In-stream storage (long- or short-term retention of sediments in the stream channel).
- Discharge or yield (movement of sediments out of the study watershed).

Land use changes and disturbances that cause increased sedimentation rates can also cause significant changes in watershed hydrology. For example, vegetation removal and soil compaction can cause a variety of hydrological changes, including changes in infiltration rates, runoff, and stream baseflows (Black, 1991; Spence et al., 1996). These hydrologic changes can increase stream vulnerability to channel and bank erosion, stress fisheries during high flows, and increase stream temperatures during dry periods.

Sample Source Assessment Framework

This general framework for sediment source assessment has proven useful in several assessment projects. Be aware, however, that specific method(s) used to estimate sources will depend on the situation.

Step 1. Define the suspected sources.
Step 2. Gather background information.
Step 3. Stratify the study area into areas of similar characteristics to simplify source assessment in each area.
Step 4. Interpret existing information and data (e.g., sequential air photography) to identify key sediment source areas and, in some cases, to develop initial source estimates.
Step 5. Develop initial sediment source flowcharts.
Step 6. Conduct field work to verify initial estimates.
Step 7. Analyze data to develop or revise sediment source estimates.
Step 8. Check results for reasonableness based on comparison with similar areas (if feasible).
Step 9. Present loading estimates for major sources and, if necessary, describe sediment transport and net yield from study areas.

(Adapted from Reid and Dunne, 1996).

Although it is beyond the scope of this protocol to address hydrologic changes associated with land disturbance, TMDL analysts should consider these effects when designing TMDLs. Refer to Reid (1996), Dunne and Leopold (1978), Satterlund and Adams (1993), Washington Forest Practices Board (1994), and Regional Ecosystem Office (1995) for additional guidance.

2. How should sediment sources be grouped?

Because sediment production is usually associated with diffuse nonpoint sources, sediment source assessment for TMDL development is often focused on source groupings rather than individual land parcels. The grouping approach is used because a parcel-by-parcel analysis is usually infeasible or extremely expensive and is not needed in all but the smallest study areas. For many sediment TMDLs, load allocations will be presented as "gross allotments," as outlined in the TMDL regulation. The gross allotments are considered appropriate when data and techniques for predicting the loading are limited. Most sediment analysis methods discussed in this protocol are based on source categories. The grouping of sediment source categories should be carefully considered in the source assessment stage of TMDL development. The appropriate selection of the various source categories will facilitate completion of the subsequent linkage analysis and allocation steps. Sources can be grouped by erosion process, controllable versus uncontrollable sources, ownership, subbasin, geology, or a combination of factors. The source categories should account for the relative magnitude of the loads, the potential management options, and the capabilities of the assessment and modeling tools under consideration. The advantages and disadvantages of different source groupings are summarized in Table 5-1.

3. What technical and practical factors affect selection of source assessment methods?

A range of sediment source estimation methods are available to assist in TMDL development. Some methods provide estimates of sediment yield for entire watersheds whereas others (e.g., the Revised Universal Soil Loss Equation, or RUSLE) provide average annual soil loss at the field scale. However, because sediment sources vary tremendously in character and importance, even within individual study areas, it might be necessary to use different methods to evaluate individual sources. The selection of the most appropriate method or methods depends on the unique characteristics of sources in the study area, how the information will be linked to other TMDL elements, and, ultimately, how sediment controls or restoration actions will be used to address the problem.

Scientific and technical considerations

Key technical factors that should be considered in the selection of methods include the proximity of key sources to waterbodies (and critical designated use areas), available data and information to support in-stream sediment storage and transport analysis, the dominant types of erosion processes and the methods available for estimating hillslope storage and delivery ratios, the timing and variability of erosion and sediment transport processes, the attenuation of sedimentation rates in response to recovery from disturbance, and the degree of natural sedimentation. Scientific factors to consider when selecting source estimation methods include the following.

Table 5-1. Advantages and disadvantages of sediment source grouping methods

Method	Advantages	Disadvantages
By Source Category (e.g., roads, streambanks, forestland, rangeland)	• Supports use of different source assessment methods for different sources, which might be more sensitive to key watershed processes which affect that source. • Supports GIS-based analysis methods that rely on stratification of source areas into land cells of unique characteristics. • Supports a differential focus of resources on key sources, yielding more precise estimates for key sources. • Allows allocation by category, which might make it easier to evaluate feasibility of controls and associated allocations. • Promotes stakeholder acceptance; helps avoid the perception of "blame."	• Different analysis methods used to evaluate individual source types might be difficult to meld and could complicate the assessment of uncertainty of cumulative analysis. • Might lead analysts to ignore key sources based on erroneous preconceptions concerning which source categories are most important. • Might not lead to easy allocations to different landowners or responsible agencies.
By Subbasin or Geology	• Allows use of sediment budgeting methods that evaluate sediment loading and yield as a function of suspended/ bedload sediment and flow by tributary. • Helps target control efforts in key problem areas, especially where most key sources are located in a few subbasins or unstable geologies. • Enables spatial association of key sources with the most vulnerable areas (e.g., key habitat areas). • Builds stakeholder support by helping to avoid the perception of blame.	• Might be useful only in estimating sediment source contributions for large areas, which could impede identification of highest-priority sources. • Often ineffective in assessing source issues where designated use concerns are located near headwaters in tributaries, and might result in missing key source problems. • If areas are too large, this method might not be capable of detecting significant sediment flux changes or effects, especially within short time intervals.
By Parcel (e.g., by individual landowner or even subset of ownership)	• Enables direct allocations to responsible landowners, thereby simplifying the task of deciding who needs to do what. • Facilitates use of much readily available information on sources often organized by land owner in GIS framework. • Promotes "trading" solutions by clarifying relative inputs from different ownerships. • Facilitates use of regulatory mechanisms (e.g., local, state, or federal discharge permits; timber harvest permits; grazing allotments; or zoning programs) to ensure that needed controls are implemented.	• Potential creation of the appearance of "locking in" allocations and removing flexibility for landowners to negotiate the most cost-effective allocation schemes. • Land ownership boundaries often follow legal boundaries without regard for geographic distinctions between land characteristics, thereby complicating source assessment on a watershed basis. • Potential perception that blame is being cast for sedimentation problems, which often diverts productive attention from problem solving.

Proximity of key sources to waterbodies

If bank erosion is considered a major and immediate threat, it might be appropriate to focus more effort on these sources and less effort on sources located farther upslope. Alternatively, it might be appropriate to make simplifying assumptions for the major sources, such as assuming that most or all eroded sediment from these sources reaches the waterbody.

Accuracy

Accuracy is important when estimates of how much eroded sediment actually reaches waterbodies within the assessment time frames (delivery ratios)are needed. Methods for estimating sediment delivery ratios include empirical estimates (see Reid, 1996, and Reid and Dunne, 1996); deriving delivery ratios as a unique function of key factors influencing sediment discharge (e.g., slope and source distance from the waterbody [Clarke and Waldo, 1986; Louisiana-Pacific Corporation, 1996]); and extrapolation from delivery ratios developed in other watersheds with similar characteristics. Method accuracy varies widely. Some methods are capable of producing estimates that are accurate to within a factor of 2 or so (Reid and Dunne, 1996). Several more resource-intensive estimation models are believed to be accurate to within 20 to 30 percent following calibration and validation (e.g., HSPF and some other relatively complex models that estimate long-term annual loads). Most modeled estimates may be accurate to only within 50 to 100 percent (e.g., monthly or daily estimates). Other methods that focus on specific sources of concern (e.g., Weaver and Hagens[1996] road assessment method) are capable of yielding relatively accurate estimates of potential future erosion volumes. Simpler, screening-level methods (e.g., models that apply simple default erosion rates or regression relationships) are believed to be capable of yielding order-of-magnitude estimates of total sediment production along with estimates of relative inputs from different sources.

Magnitude of source type

Methods should be focused on areas where designated uses of concern are localized (e.g., spawning areas or favored swimming areas). In these cases it might be appropriate to focus the source assessment on upland areas near or upstream from the waterbody area of concern (Washington Forest Practices Board, 1994).

Erosion process

In-stream storage and transport analysis should be accounted for when the net sediment yield from the watershed is a TMDL indicator, the in-stream channel structure and function have been disrupted by sediment discharges, a large volume of sediment from past discharges is working its way through the system, a large proportion of total sediment in the system is stored in-stream, or geomorphic analysis is needed to design restoration actions. In-stream storage and transport analysis is less important when the major project concern is long-term sediment loading (e.g., to a lake or estuary), indicators that do not focus on sediment loading (turbidity) are used, and the project focus is long-term erosion prevention (i.e., in-stream sediment dynamics are of lesser concern).

When upland sediment storage substantially reduces the amount of sediment that reaches streams or changes the timing of sediment delivery, it is usually important to select methods that account for upslope sediment storage or estimate the sediment delivery ratio (the percentage of eroded sediment that actually reaches the waterbody). Although the use of "rule of thumb" sediment delivery ratios should be used with caution since it is based on long-term averages extrapolated from lake studies.

Sediment source assessment methods should be selected based on a clear understanding of the dominant sediment-producing processes active in the watersheds of concern. For example, in many parts of the Northwest, Southwest, and Pacific Islands, erosion processes tend to be associated with occasional large storm events. Sediment discharges tend to vary substantially from year to year in such settings. In contrast, sediment discharges of concern are associated with more regular precipitation and flow events in most other parts of the country. Approaches available to account for erosion associated with regular runoff patterns or relatively frequent high-flow events (e.g., with 1- to 3-year return periods) usually estimate sedimentation as a function of the distribution of rainfall or flow events of different magnitudes and provide cumulative erosion estimates.

In watersheds dominated by very infrequent but extreme runoff and sedimentation events, erosion is substantially more difficult to predict. In these cases, it might be preferable to select methods that estimate erosion potential but do not attempt to directly estimate erosion associated with specific future high-magnitude events (see, for example, Weaver and Hagens, 1996). Alternately, the TMDL could specify longer time steps for averaging sediment inputs (e.g., as rolling averages over a 5- to 15-year period) to account for interannual variability in erosion rates.

Land management

Sedimentation rates associated with some land uses (e.g., timber harvesting, construction, and some cultivation practices) typically decline over time after the land disturbance occurs and the land has a chance to recover. To account for potential attenuation in sedimentation rates in these cases, a sediment source assessment might need to incorporate an attenuation factor to avoid overestimating future erosion. Recovery rates should be based on analogous local or reference watershed experience whenever possible. Where recovery rates used to estimate erosion attenuation are based on general sources, a substantial margin of safety might be needed to ensure that future sediment loads are not underestimated. (See Reid, 1996; McGurk and Fong, 1995; and Berg et al., 1996 for further information and examples.) Sedimentation rates from farmland in crop rotation can vary depending on the stage of crop rotation.

The likelihood and timing of future land disturbances should be considered. Although a watershed can sometimes recover from one-time or widely disbursed disturbances, the cumulative effect of multiple disturbances may be that sedimentation rates remain above levels of concern for decades or longer (see Berg et al., 1996).

A source assessment might not need to define a specific recovery or attenuation function. An analysis could link individual estimates of sediment yield per disturbance action (e.g., discrete timber harvesting event) with overall targets above which watershed sediment yield is excessive in any single period of time (Lewis and Rice, 1989, 1990; Louisiana-Pacific Corporation, 1996). If the per entry factor and the sediment threshold are linked, the variable management factor would be the number and spatial distribution of timber harvest entries and reentries planned in a watershed.

Background loading

Some erosion occurs in all watersheds, even those which are completely undisturbed. Some watershed types are extremely prone to periodic major sedimentation events. Designated uses located in such settings have often adapted to naturally high sediment conditions.

TMDLs need to distinguish sedimentation rates associated with human activities in the study watershed from those associated with naturally occurring (and presumably uncontrollable) sediment sources. Human land management activities can change the magnitude, locations, and timing of land erosion or runoff events as well as the key physical characteristics of receiving waters. Methods sensitive to changes in the driving forces that influence sedimentation (e.g., models like RUSLE, HSPF, and WRENSS) will be useful in comparing natural and anthropogenic sources if data about key processes are available for the TMDL study area and reference watersheds.

Methods that estimate sediment loading or yields as a function of sediment concentration and streamflow (e.g., rating curves) are less useful in evaluating how existing sedimentation rates differ from natural sedimentation rates. Where rating curve methods are used, careful comparison to reference watersheds (and the underlying differences in land use or land characteristics) can assist in comparing natural and human-caused sedimentation.

Direct erosion prediction methods might be able to assess the degree to which erosion likelihood has, as a result of human activity, been increased (e.g., due to road construction in a vulnerable area) or decreased (e.g., due to stabilization of an existing landslide feature).

Practical considerations

Practical considerations include resources available compared to level of effort needed to analyze the sources, level of accuracy desired for the TMDL, and stakeholder involvement and concerns. For most TMDLs, the selection of appropriate methods for TMDL development will rely on a combination of scientific and practical considerations.

Practical considerations include the following:

- Carefully consider data and resource demands associated with all methods. Methods that require unavailable technical expertise, data, or time should not be selected.
- Assume that existing data will be adequate to develop a reasonable first-phase source assessment. (Plan according to the data in hand.) Relatively crude estimates of sediment input sources might provide adequate results for many TMDLs.
- Complex source assessment tools might be most appropriate only where costs of controlling or restoring sources are expected to be very high and where refinement of source estimates might substantially change allocations.
- Source assessment methods should be understandable (e.g., models perceived as "black boxes" are often difficult to explain), sensitive to or capable of building upon previous local source assessment work, and logically linked to other TMDL elements.

4. What is the appropriate source assessment method?

This section provides information on a range of potentially useful sediment source assessment methods that have been developed to

- Estimate actual or potential loading from hillslopes and banks to receiving waters.
- Evaluate in-stream storage and transport of sediment.
- Estimate the net sediment discharge (or yield) from drainage basins.

The degree to which individual sediment TMDLs address erosion and waterbody impairment by sediment will depend on the overall approach taken in the TMDL (e.g., the designated uses of concern, types of numeric targets developed, key sources of concern, and land management actions under consideration). Each type of approach has its pros and cons. In general, methods that more thoroughly account for both hillslope sediment production and sediment transport and fate after erosion occurs are likely to prove more useful in identifying the sediment assimilative capacity of waterbodies than methods that focus only on upslope source assessment. However, other methods to assess assimilative capacity and plan needed responses are available and are potentially more cost-effective than full-scale sediment budgets. In watersheds where past sediment budgeting has been done, analysts should clarify the scope of the work performed and take care not to assume that a particular type of analysis was performed.

Source assessment methods

Source assessment methods vary widely with respect to their applicability, ease of use, and acceptability. Recognizing that many source assessment methods exist, summaries of the methods were developed for several categories. In some cases, the categories contain a range of models that could arguably be placed into multiple categories. The following categories are based on expected uses of these methods in estimating soil erosion, storage, and delivery in the context of TMDL development:

1. Indices (do not provide load estimates but do provide a guide for the TMDL)
   - Vulnerability
   - Future erosion
2. Erosion models
   - Source loading
   - Source loading and delivery processes
3. Direct estimations
   - Sediment budget
   - Rating curves
   - Statistical extrapolation

The following summaries present the key attributes of the methods, review key advantages and disadvantages, and make general recommendations concerning the use of the model type for TMDL analysis.

Source sensitivity and erosion potential estimation methods

A variety of methods are available for evaluating land vulnerability, or sensitivity to erosion, sometimes as associated with specific land management activities. These methods do not directly yield sediment loading estimates, but they can be used effectively to compare the relative vulnerability of different areas to future erosion or to target field work to make empirical estimates of erosion potential. Some of these methods yield indices or measures of watershed conditions that might be associated with designated use condition (e.g., Equivalent Roaded Acreage [McGurk and Fong, 1995]), although these associations are poorly documented in most parts of the country. It is possible to derive methods that can provide such associations as both a component of source assessment and a numeric target to complement in-stream targets (see Chapter 4).

Most of these methods have been developed to address watersheds in which timberland management and fishery issues are primary concerns, although some habitat condition inventory methods have similar characteristics. This section briefly discusses examples of methods that focus on sources that are often important sediment causes.

Watershed analysis techniques have been developed to evaluate watershed resource values, land use activity impacts on those values, and opportunities to protect and restore resource values through land use management and restoration planning (e.g., Regional Ecosystem Office, 1995; Washington Forest Practices Board, 1994.) Washington's Timber, Fish and Wildlife (TFW) 1994 approach entails assessments of watershed condition according to key watershed processes with a focus on fishery resource protection. Process assessments are converted into numeric ranking factors. Multiple ranking factors are then synthesized to yield relative vulnerability rankings for different parts of the study area, which then assist resource managers in developing specific management and restoration approaches or prescriptions.

The federal agency watershed analysis approach focuses on a broader range of watershed and resource management issues than fisheries and timberlands, and it provides a general framework for quantification and synthesis of watershed process assessment evaluations. Unlike the TFW approach, the federal process is not a decision-making process intended to lead directly to land management planning decisions. Both the TFW and federal watershed analysis approaches provide opportunities to gather and evaluate information concerning the relative significance of sedimentation and sediment sources in a watershed, but they do not necessarily yield quantitative estimates of past or future sediment production.

Erosion vulnerability methods do not produce erosion or sediment yield estimations, but instead index the potential effects, including cumulative impacts of management actions. Because sediment generation is usually a major impact of forestry operations, these methods can provide useful information in these settings. For example, the Equivalent Roaded Area (ERA) approach indexes potential impacts expected from each activity to that expected from roads (USDA Forest Service, 1988). A land use history is developed for the watershed, sensitive sites are identified, and ERAs are calculated for each activity with respect to the mechanism thought to be of greatest concern. Values are summed and normalized by area to calculate a total ERA percentage, which is compared to an allowable threshold identified for the watershed. If the calculated ERA value is higher than the threshold, the watershed may be singled out for further evaluation by other means. Similar approaches have been used in other parts of the country, including Equivalent Clearcut Area (see Berg et al., 1996). In addition, specific disturbance measures have been used to help characterize relative erosion vulnerability in different subbasins within a watershed study area (e.g., Black Butte River, California, Watershed Analysis).

A simple forestland erosion hazard rating system developed by the California Department of Forestry (1990) evaluates the relative sensitivity of different land areas to erosion as a function of soil characteristics, geology, slope, vegetation, and rainfall ranges. This approach produces maps of erosive hazard to guide planning and field assessments in forestlands. Landslides and other mass wasting features are critical sources of erosion in many parts of the country. One mass wasting assessment model used in the Pacific Northwest estimates sensitivity of land areas to shallow landslides as a function of precipitation, soil characteristics, and topography (Dietrich et al., 1992, 1993; Montgomery and Dietrich, 1994). Based on analysis of aerial photographs, geologic and landslide maps, and digital elevation data, needed model inputs can be developed. The model is capable of landslide sensitivity rating maps and measures of slide areas, and associated GIS coverages. This method has been used in several watershed analysis projects in the Pacific Northwest and California. Table 5-2 summarizes advantages and disadvantages of this category of methods.

Assessing future erosion requires identifying key erosion features based on aerial photography analysis or another screening method, then making field-based measurements of erosion potential of the largest future sediment sources while evaluating the prospects for restoration or mitigation actions. Most of the settings in which this approach has been applied are Pacific Northwest forest settings dominated by erosion associated with logging roads and associated mass wasting features (e.g., Redwood National Park, California). It has not been extensively applied outside this general setting, but it has the potential to address watershed settings where other source concerns predominate. Generally, these methods do not directly predict when the erosion activity will occur; instead, they target the assessment of key erosion features and evaluate the feasibility of avoiding or mitigating the future erosion effect (Weaver and Hagans, 1996). The theory underlying this approach is that it is more efficient to target future erosion sources for remedial action than to evaluate past erosion locations, which are probably not amenable to productive treatment. In addition, the method probably works best in settings where a relatively small group of potential sediment sources will be responsible for most future erosion (e.g., road failures and mass wasting features), in contrast to watersheds where erosion contributions are spread evenly across the landscape (e.g., sheet and rill erosion from cultivated land).

Recommendations: Where these methods have been used extensively, analysts should consider exploring ways to use the results in TMDL development or assessment priority setting. Creative application of these results could fit well with one or more TMDL elements and could significantly assist in source assessment. It is unlikely that any of these methods provides a substitute for source measurement or estimation through one or more of the other methods discussed in this section. Future erosion estimation has not been widely applied to date, but it offers great promise for TMDL development in many settings. The method is particularly appropriate in settings where catastrophic sedimentation events are likely in key disturbed areas in association with catastrophic events (e.g., major storms and rain-on-snow events). The method is less likely to be cost-effective in very large watersheds (due to the prohibitive costs of field work) or where highly disbursed erosion sources triggered by commonplace driving forces predominate. However, it might be feasible to use the approach in larger watersheds if field work is targeted based on watershed stratification and preliminary screening analysis (Reid and Dunne, 1996).

Erosion process methods

Erosion process methods generally estimate sedimentation through the application of sedimentation prediction algorithms or erosion hazard ratings for different land parcels. Most of these methods apply models that estimate erosion as a function of several key factors, potentially including soil characteristics, topography, vegetation characteristics, and precipitation. Many available methods are based on the Revised Universal Soil Loss Equation (RUSLE) or one of its many variants as applied by many agencies for erosion estimation over the past decade (e.g., AGNPS, SWRRBQ). Other methods commonly apply particle detachment and washoff equations to estimate erosion (e.g., HSPF, CREAMS, ANSWERS). Erosion process models vary substantially in the sophistication and technical expertise necessary to ensure proper application. Table 5-3 presents a summary of the basic differences in method sophistication.

This discussion distinguishes between models that focus only on hillslope erosion (source loading models) and models that account for both erosion and transport of sediment out of the watershed (source loading and in-stream process models).

Source loading models

Several commonly used methods provide estimates of erosion from multiple sources, hillslope storage, and sediment delivery to streams. Methods that have been applied successfully include, but are not limited to, the following:

- USLE/RUSLE
- AGNPS
- BASINS-NPSM
- WATSED
- BOISED
- Critical Sites Erosion Study (CSES)
- WEPP
- HSPF
- SWAT

Table 5-2. Advantages and disadvantages of source sensitivity estimation methods.

Advantages	Disadvantages
• Provide method for assessing relative significance of sediment sources or source areas in settings where quantitative estimation of past or future sediment sources is difficult due to the unpredictability of erosion timing or magnitude or the difficulty of conducting adequate field work. • Provide priority-setting framework for future assessment and management planning. • Might be possible to establish thresholds of concern for certain vulnerability measures, which could be used to develop numeric targets and to assess need for source controls.	• Measures of vulnerability and sensitivity do not yield direct measures of past or future sedimentation from specific sources, which might be easiest to use for TMDL development. • Use of these approaches for prediction purposes has not been well established in most cases or has been explicitly discouraged (e.g., Equivalent Roaded Acreage). • Require substantial expertise to develop correctly and should include field work as part of the analysis (which increases costs). • Accuracy of surrogate vulnerability measures has not been confirmed in many settings. For many parts of the country (e.g., where forest land issues are not critical), these methods have not been used at all.

Many models based on methods similar to the RUSLE (Renard et al., 1997) have been used effectively to evaluate erosion from cultivated areas in the East, Southeast, and Midwest. Extensive discussion of these methods is provided in USEPA (1997c) and is not repeated here.

Source estimation models vary substantially in analysis time steps. Some models (e.g., AGNPS and ANSWERS) evaluate runoff associated with single precipitation events, whereas others (e.g., HSPF and SWAT) simulate sediment loadings using hourly or daily time steps for longer time periods. Analysts should be sensitive to the different time steps used by models and should consider how the results of single-event simulations will be integrated across time, ensuring loadings are consistent with TMDL allocations. Similar models such as BOISED, WATSED, R1/R4, and WRENSS have focused primarily on forested watershed sediment analysis. These models segment watersheds into land types and land system inventories. Each land parcel in the watershed is allocated erosion hazard

Table 5-3. Erosion process model comparisons.

Model Type/Examples	Key Capabilities and Limitations
Simple Methods: EPA Screening Procedure USGS Regression Procedure RUSLE WEPP	• Aggregate large land areas (not RUSLE) • Large time steps, e.g., average annual (not RUSLE) • Estimation methods based on empirical relationships and expert judgment • Do not model delivery processes. • Generally reliable only for relative comparisons of sources, not load estimates • Limited data; no calibration requirements
Mid-Range Models: BASINS-NPSM AGNPS ANSWERS R1/R4 WATSED BOISED WRENSS SWAT	• Compromise between empirical and mechanistic models • Reliable for order of magnitude accuracy • Can interface with GIS framework • Moderate data and calibration requirements • Some capable of evaluating transport and/or control effectiveness
Detailed Models: HSPF SWMM SWRRBQ ANSWERS SWAT CREAMS	• Can delineate sources at fine parcel scales • Can evaluate short time sequences/individual storm effects • Generally use mechanistic representations of key watershed functions to estimate erosion • Estimates generally accurate within factor of 1 to 2 • Often work best in interface with GIS framework • Substantial data and calibration requirements • Usually capable of evaluating transport and/or possible control effectiveness

potential and sediment delivery ratio values that allow generation of erosion curves for each disturbance source on the watershed. Estimates for this information are ideally based on field information collected for the specific purposes of the model. Absent such field data, potential sources of information include erosion plot studies, special-purpose studies (e.g., road and trail erosion assessments), soil maps, erosion hazard potential maps, Watershed Improvement Needs surveys identifying disturbance types and sources, and fish habitat surveys. As part of their routine operations, land management agencies typically generate these types of data sets.

A variation on these approaches is the Critical Sites Erosion Study, a method that estimates the probability that a site will yield more than a given sediment load if the land is disturbed by timber harvest or road construction (Lewis and Rice, 1989). This method was used in a recent large-scale watershed assessment by Louisiana-Pacific Corporation to evaluate potential impacts of future timberland management plans (Louisiana-Pacific Corporation, 1996). This method recognizes that erosion in many settings is not even and that the majority of measured erosion in such settings comes from a relatively small number of critical sites. In such settings, this type of method potentially enables the analyst to focus on the watershed land areas most likely to become major erosion sources and to obtain more accurate estimates of potential sediment discharge.

Table 5-4 summarizes advantages and disadvantages of hillslope source models for TMDL source assessment.

Recommendations: Erosion process models that focus on upland areas can yield reasonable results for TMDL analysis. They are appealing in many cases because they can be applied without having to do extensive field work. These models are probably most effective for source analyses where the models have been applied and calibrated in the past, where sediment fate and transport after delivery is a less critical issue, and where sedimentation is associated primarily with sheet and rill erosion from relatively low-sloped lands. For example, these methods typically work well in settings where cropland erosion drains directly to reservoirs or lakes. The broad, successful use of such models suggests that they can be made to work within many project settings.

Such models should be used with caution in cases where extreme watershed conditions predominate (e.g., very steep topography, landslide-dominated erosion, radically variable precipitation regimes). Other methods (e.g., R1/R4, WATSED) might be preferable in many mountainous regions, the Pacific Northwest, and very arid terrains (e.g., RUSLE). Where hillslope source models are used, it is crucial either to calibrate and subsequently validate the models to ensure reasonable accuracy or to conduct follow-up monitoring to check the reliability of the earlier results.

Table 5-4. Advantages and disadvantages of hillslope source models.

Advantages	Disadvantages
• Widely used in many parts of the country (especially the RUSLE-based approaches). • Well accepted as a sediment prediction tool in many circumstances. • Detailed default parameters for many of the key model inputs are widely available, which facilitates use of these approaches without having to collect extensive data in many circumstances. • Needed data (e.g., soil composition) are widely available for many parts of the country. • Provide relatively coarse or fine estimates of erosion depending on project needs, spatial scales, and time steps chosen. • Simple methods can yield useful estimates of the relative importance of different source areas, which might be sufficient for some TMDLs. • If more sophisticated models are used, it might be possible to evaluate the relative sensitivity of different model factors in affecting future erosion predictions. Based on such sensitivity analysis, it might be possible to target controls or restoration at factors most responsible for erosion effects.	• Generally do not address or account for bank erosion. • Generally do not clearly account for hillslope sediment storage and routing. • Downslope transport analysis often does not consider actual complexity of transport processes. • Accuracy questionable for extremely steep watersheds in which sedimentation is dominated by extreme climatic or geologic events. • Do not assist in the analysis of sediment fate after sediment reaches waterbodies of concern, which may ignore key TMDL issues or require additional in-stream analysis, especially linkage analysis. • Generally predict average annual or monthly gross loading rates.

Source loading and delivery process models

Source loading and in-stream process models can be used to estimate sediment erosion from multiple source categories and movement to the water's edge (as with the hillslope models described above). In addition, they can provide a gross accounting of sediment transport and in-stream storage to provide useful information about net sediment yields from a watershed and information about in-stream sediment fate (e.g., gross degradation or aggradation). Care should be exercised when using the transport and storage component of these models because significant uncertainty is inherent in the model results (e.g., erosion processes such as streambank erosion are not accounted for in the models). Models that incorporate both upland and in-stream sediment analysis components include HSPF, SWMM, SWRRBQ, DR3M, WRENSS, and SWAT. Table 5-5 summarizes advantages and disadvantages of the hillslope source and in-stream process models.

Recommendations: Given the relatively high cost, expertise, and effort associated with using these models, they are most appropriate for large-scale watershed projects with substantial, long-term resource support and stakeholder commitment. The level of detail and precision these models can provide are worthwhile in settings where prospective sediment control and restoration costs are high and stakeholders do not agree on the best ways to proceed. The ability of these methods to provide net sediment yield estimates may prove useful in settings where the detailed field work needed to complete some types of sediment budgets is infeasible. In settings dominated by occasional extreme-magnitude sedimentation and runoff events, however, it might be best to assemble different source assessment and sediment transport analysis methods for individual sources of concern and combine the results to construct sediment budgets. (See Reid and Dunne [1996] for information on this approach.)

Direct measurement methods

These methods differ from the preceding methods because the analysis is based on direct measurements of past erosion rates and amounts. The general strategy of this approach is that information on past erosion can be used to characterize trends, to help predict future erosion amounts, and to plan appropriate restoration and prevention actions. Sediment budgets as described by Reid and Dunne (1996) provide information on individual source measurement methods and references.

Reservoir studies have been widely used to measure overall watershed sediment yields and discharge rates over time. This method entails the estimation of sediment displacement of reservoir capacity over time to yield a measure of total mass loading or watershed loading rates over time. For example, one study calculated estimated total sedimentation rates per square mile of watershed area in Northern California coastal ranges based on reservoir studies (Phillip Williams Associates, 1996).

Table 5-5. Advantages and disadvantages of hillslope and in-stream process models.

Advantages	Disadvantages
• Ability to evaluate sediment fate in streams makes it possible to more precisely identify when and where in-stream sediment loads are expected to occur, and to evaluate designated use impacts as a result. • Helpful in cases where a substantial lag time between the onset of erosion and the transport of sediment to key areas exists. • When used in concert with geomorphic analysis methods, model results can assist in evaluating how changes in sedimentation and hydrology associated with land use changes affect channel structure and function. • Assist in evaluating prospective effectiveness of different source control or restoration methods. • Relatively widely used in urban settings. • GIS interfaces often available to facilitate management of large data sets.	• Substantially more complicated to use than the models in the preceding group. • Large amounts of local data are generally needed to calibrate and validate the models. • Relatively little experience exists in their use. • Have not been widely used to examine rural or wildland settings. • Do not account for changes in stream morphology and sediment transport capacity associated with long-term change in erosion and hydrologic processes. • May need separate geomorphic analysis to evaluate the need to make future changes in channel profile inputs to these models. • Difficult to predict transport and storage accurately, particularly in large watersheds.

At a smaller scale, many methods are available for directly estimating erosion from sources such as:

- Bank erosion.
- Slope erosion from timber harvest, construction or other activities.
- Headcut or gully erosion.
- Landslides.
- Road erosion and road-related mass wasting.
- In-stream sources, including channel scour.

These methods usually entail the measurement of eroded areas, placement of sediment traps to catch sediment moving downhill, and/or pins or scour chains to detect the removal of sediment from stream channels over time. In many cases, hillslope sediment volumes can be directly measured or inferred by measuring void spaces or erosion around datable vegetation. Advantages and disadvantages of these methods are summarized in Table 5-6.

Recommendations: This group of methods can be very useful to build an overall estimate of sediment loading rates (e.g., reservoir studies), to evaluate erosion patterns associated with specific sources (based on bank or upslope erosion estimates) or areas (based on comparisons between source monitoring done in different areas), or to validate estimates derived using other methods (particularly sediment budgeting methods). In general, these methods should not be uniformly assumed to provide reliable future erosion estimates given the potential future variability of key watershed processes.

Rating curves and other statistical extrapolation methods

Rating curve methods generally estimate total sediment loading past a measurement point as a function of three variables—streamflow, suspended sediment concentration, and bedload transport. Separate suspended load and bedload rating curves are developed in many cases, and bedload rating curves are often not developed because of bedload sampling difficulties. Functional relationships among these variables are usually estimated through regression analysis and used to estimate average annual or seasonal sediment loading. For example, in a situation where a modest number of data points are available relating flow, TSS, and sometimes bedload, it is often feasible to develop statistically reliable regression functions. Then, the overall sediment load can be estimated by applying

Table 5-6. Advantages and disadvantages of direct measurement methods.

Advantages	Disadvantages
• Provide direct measures of sedimentation from specific sources. • Over long time scales, can be used to develop estimates of long-term erosion rates in some cases. • Effectively complement the use of other source estimation methods that do not address all sources of concern (e.g., Sycamore Creek, MI, study directly measured bank erosion to complement modeled estimates of erosion from agricultural and urban areas). • May be possible to derive useful results for some sources by establishing collection traps or pins, then measuring the results annually or seasonally, if longer time steps are acceptable for TMDL development. • Reservoir studies can provide a more accurate means of estimating the relative proportion of total sediment load that moves downstream as bedload and as suspended load (Reid, 1996). • Reservoir studies can provide fairly reliable long-term average loading rates per unit area of watershed in many places (which can also assist with model validation or establishment of reference conditions.) • Some data are better than no data. • Can apply results to other, analogous areas. • Can use data to calibrate/validate models. • Easy to measure sediment in areas where landslides are responsible for most sediment.	• Direct measures are often time- and resource-intensive to develop. • Difficult to generalize based on data collected because it is difficult to determine if sampling sites are representative of watershed conditions as a whole or of similar sources within the watershed. • Sediment traps can miss substantial amounts of sediment eroded uphill if they are spaced too widely or if sediment moves through channels or gullies that pass between traps. • Many watersheds of interest for TMDLs either have no reservoirs to study or have no nearby watersheds containing reservoirs for use in establishing sedimentation rates based on analogous circumstances. • Past erosion rates and total loadings might provide a poor basis for estimating future rates and loadings if key watershed processes or characteristics change in the future. • Past erosion evaluation might miss substantial erosion potential if monitoring is not done during time periods when most erosion occurs (often the case with site-specific erosion studies that do not account for the effect of extreme climatic or runoff events).

these functions to a continuous (or more frequently monitored) flow record based on the frequency distribution of flows of different magnitudes. For example, a sediment budget was developed for the Trinity River, California, based on the rating curve method (USDOI-BLM, 1995). Refer to USDA Agricultural Research Service (1975) for additional information on using rating curves to estimate sediment yield.

Variations on the traditional rating curve approach include the following:

- Annual rating curves, which may facilitate analysis of changes in sediment yield associated with land management changes or temporal variability (Ketcheson, 1986).
- Time-integrated rating curves, which ignore streamflow fluctuations and integrate sediment transport rates over time (Ketcheson, 1986).
- A sediment supply-based model that uses a suspended sediment rating curve and supply depletion function to account for load declines during individual storms or runoff seasons (Van Sickle and Beschta, 1983).

Similar methods might be available to extrapolate localized sediment loading information. For example, a sedimentation load or rate estimated for one tributary area of a larger watershed could be used to estimate an overall load or rate for the rest of the watershed if key characteristics of the smaller study unit and larger watershed are comparable and flow data are available for the larger watershed. Care should be taken in extrapolating results derived for a small area to a larger watershed area, or from a short time period to a longer time frame, to account for differences in operation of key watershed processes (e.g., hydrology and precipitation) at larger spatial scales or within longer time frames. Table 5-7 summarizes advantages and disadvantages of rating curves and other statistical extrapolation methods.

Recommendations: Used with care, rating curves and other extrapolation methods can provide a cost-effective approach to source assessment, particularly in large-scale TMDL studies where tributary-by-tributary source analyses are adequate. Rating curve approaches are particularly appealing in areas where they have been used in the past or are commonly used by stakeholder agencies and groups. This method is less appropriate in systems where sediment discharge is dominated by infrequent, large-magnitude events (e.g., mass wasting and flood events triggered by extreme precipitation events because the flow-TSS relationship observed at lower flows might not account for these processes.

Rating curve construction should be preceded by careful suspended sediment sampling covering a representative range of storm or runoff events, if possible. Bedload sampling (or an appropriate substitute method of estimating the bedload portion of the total load) should also be considered (see Reid and Dunne, 1996; Rosgen, 1996). Analysts should validate and refine rating curves over time to account for changes and improvements made possible by additional monitoring. Finally, it might be appropriate to complement rating curve analysis with more detailed source assessment in the highest-priority sediment source tributaries identified by the rating curve analysis, as a later phase of the TMDL project.

Comparisons of source estimation methods

Source assessment method selection requires careful consideration of the unique mix of issues, opportunities, and characteristics present in each watershed, and it is inappropriate to select methods based solely on the cursory evaluations provided in this document. Analysts are encouraged to use this information as a starting point and to consult key references and local experts for assistance in the final selection of methods.

5. How do estimated source contributions compare with natural or background levels?

Where feasible, the source assessment should also compare projected sediment loadings with natural or background levels of sediment loading. This type of comparison greatly facilitates the linkage of sediment source assessment with numeric targets. (See Chapter 6 for details on linkages.) A sediment loading comparison provides an additional basis for determining the degree to which sediment loadings differ from levels needed to support designated uses, thereby assisting in identifying the needed levels of sediment reduction. In many settings it is possible to estimate natural or background sediment production in the study area. Such estimates can be developed by assessing sedimentation rates measured in relatively undisturbed areas of the

Table 5-7. Advantages and disadvantages of rating curves and statistical extrapolation methods.

Advantages	Disadvantages
Rating Curves • Widely used. • Based on locally obtained empirical information. • Substantial degree of statistical validity. • Ability to relate suspended, bedload and total sediment loading (frequently subdivided by tributary watershed) offers a ready method of linking a commonly used sediment endpoint (suspended sediment or turbidity as a surrogate) to a source estimation tool. • Sensitive to spatial and temporal variability in sediment loading (by relating loads to flows) (e.g., Deep Creek, MT). • Reasonably accurate for estimating source loads on tributary-by-tributary basis. Other Extrapolation Methods • Statistical extrapolation methods allow screening-level source analyses for large land areas without having to invest in detailed analysis of each land area. • Assists in targeting the most significant source areas of concern for further assessment and action without waiting for the results of lengthy detailed analysis.	Rating Curves • Data sources needed for rating curves (flow, suspended sediment, and bedload sediment) are highly variable and often difficult to measure accurately. • Statistically significant results are often difficult to obtain. • Unless careful sampling designs are followed, it is easy to obtain a skewed sampling of sedimentation events, which could easily lead to underestimation or, occasionally, overestimation of sediment loading. • Bedload factor is often misinterpreted. Proportion of sediment transported in bedload varies widely among stream types and between events within a stream. • Rating curve approaches that ignore bedload or assume a bedload portion of total load without careful analysis are likely to produce inaccurate results (Reid and Dunne, 1996; Rosgen, 1996). • Rating curve approach does not help analyze key watershed processes influencing sediment production. • Difficult to determine respective influences of sediment supply and channel transport capacity on changes in sediment yields. • Might not assist in source assessment by source category ownership; tributary scale might not be fine enough. Other Extrapolation Methods • Key statistical assumptions that should be met to draw robust conclusions are not met in many studies (e.g., flow and discharge data points are often *not* independent of each other). • Easy to miss fundamental differences in the characteristics of small study areas and the larger land areas or time scales for which extrapolations are developed. Where differences are not taken into account, large, difficult-to-detect errors might occur.

watershed or in comparable reference watersheds, or estimated based on reviews of appropriate literature sources. (See Reid and Dunne [1996] for additional information.) These comparisons might not be absolutely necessary for all TMDLs, particularly where other methods are available for clearly determining the degree to which existing and projected sedimentation conditions depart from target levels.

6. How can the source assessment be described for TMDL submittal?

The source assessment should yield estimates of sediment loading from different sources within the study area. These results can be expressed in terms of expected sediment loadings per unit of time. If the source assessment results are expressed in terms other than mass loads per unit of time, the TMDL should describe why the alternative approach is used. In addition, if the source assessment also includes evaluations of in-stream sediment fate and transport and/or net sediment yield from the watershed, the TMDL should describe these results. Ideally, the source assessment results include estimates of sediment loading in total and by source, taking into account temporal variations in sediment delivery. Finally, if the source assessment includes comparisons of projected and natural or background sediment loadings, these results should also be presented in the TMDL document.

7. What changes does the proposed rule speak to?

On August 23, 1999, EPA published proposed rules that specify that approvable TMDLs must include at a minimum ten elements. Within the source assessment step, an approvable TMDL will need to include an identification of the source categories, source subcategories, or individual sources of the pollutant for which the wasteload allocations and load allocations are being established.

RECOMMENDATIONS FOR SOURCE ASSESSMENT

- Using all available information, develop a comprehensive list of the potential and actual sediment sources to the waterbody. Develop a plan for identifying and accounting for the load originating from the identified sources in the watershed.
- Use GIS or maps to document the location of sources and the processes important for delivery to the waterbody.
- Identify all government agencies and non-government organizations active in the watershed and conduct interviews and collect information.
- Group sources into some appropriate and manageable unit (e.g., by delivery mechanism, location, rate) for evaluation using the available resources and analytical tools.
- Ideally, monitoring data should be used to estimate the magnitude of loads from various sources. In the absence of such data, some combination of literature values, best professional judgment, and appropriate empirical techniques or models will be necessary. In general, the simplest approach that provides meaningful predictions should be used.
- Sediment source assessment methods should be selected based on a clear understanding of the dominant processes in the watershed.

RECOMMENDED READING

(Note that the full list of references for this chapter is included at the end of the document.)

- Dissmeyer, G.E. 1994. *Evaluating the effectiveness of forestry best management practices in meeting water quality goals or standards*. USFS Miscellaneous Publication 1520. U.S. Department of Agriculture, Forest Service, Washington, DC.

- Regional Ecosystem Office. 1995. *Ecosystem analysis at the watershed scale. Version 2.2.* U.S. Government Printing Office: Regional Ecosystem Office, Portland, OR. 1995-689-120/21215.

- Reid, L.M., and T. Dunne. 1996. *Rapid evaluation of sediment budgets*. Catena Verlag, Reiskirchen, Germany.

- USEPA. 1997. *Compendium of tools for watershed assessment and TMDL development*. EPA 841-B-97-006. U.S. Environmental Protection Agency, Washington, DC. <http://www.epa.gov/owow/tmdl/techsupp.html>

- Washington Forest Practices Board. 1994. *Standard methodology for conducting watershed analysis under chapter 222-22 WAC*. Version 2.1, November 1994. Washington Forest Practices Board, Olympia, WA.

AR0023061

Linkage Between Water Quality Targets and Sources

Objective: Define a linkage between the selected water quality targets and the identified sources to determine total assimilative capacity for sediment loading or total load reduction needed.

Procedure: Determine the cause-and-effect relationship between the water quality target and the identified sources through data analysis, best professional judgment, models, or previously documented relationships. Use the linkage to determine what sediment loads or conditions are acceptable to achieve the desired level of water quality. Develop approaches for determining an appropriate margin of safety.

OVERVIEW

One of the essential components of developing a TMDL is to establish a relationship (linkage) between the indicators and numeric targets and the estimated loadings. This linkage makes it possible to determine the capacity of the waterbody to assimilate sediment load and still support its designated uses. Based on this analysis, allowable loads or needed load reductions can be allocated among key sources. The link between in-stream uses, as evaluated through numeric targets, and sources, as evaluated through the source analysis, can be established by using one or more analytical tools. Ideally, the link will be based on long-term monitoring data that indicate the waterbody's response to flow and loading conditions. More often, however, the link must be established by using a combination of monitoring data, statistical and analytical tools (including simulation models), and best professional judgment. It is difficult to draw accurate linkages between hillslope processes and in-stream conditions, and it will be necessary at times to base linkages on qualitative analysis relying on professional judgment.

Key Questions to Consider for Linkage of Water Quality Targets and Sources

1. What is an appropriate level of analysis?
2. What is an appropriate method for linkage?
3. What is the linkage and what is the resulting estimated loading capacity or needed load reduction?

This section provides recommendations regarding appropriate techniques for establishing the source-indicator link. As with the prediction of sources, the analysis can be conducted using methods ranging from simple to complex.

KEY QUESTIONS TO CONSIDER FOR LINKAGE BETWEEN WATER QUALITY TARGETS AND SOURCES

1. What is an appropriate level of analysis?

Choice of an analytical tool to link the sediment loads to the TMDL indicator(s) depends on the interaction of a number of technical and practical factors. Suggestions on how to address these factors were included in the numeric targets and source analysis chapters and are not repeated here. Key factors to consider in determining the appropriate level of analysis for TMDL linkages include the following:

- The types of indicators and source analysis tools used in the sediment analysis, and other watershed processes that influence sedimentation dynamics in the study area.
- Physical and hydraulic characteristics of the waterbody (e.g., lake versus stream).
- Geomorphic characteristics of the waterbody and degree to which waterbody structure is stable.
- Temporal representation needs. (Are seasonal averages sufficient, or must dynamic events on a shorter time scale or key time periods [e.g., fish life stages] be evaluated?)
- Spatial representation needs. (Are there significant spatial variations in the indicator and does spatial variability in the waterbody [e.g., key spawning areas] need to be represented?)
- User requirements (including availability of resources, time constraints, and staff familiarity with specific analysis techniques).
- Stakeholder interests and outreach needs.
- Level of accuracy needed.

Different TMDLs will need varying degrees of accuracy in establishing linkages between sediment sources and in-stream targets, depending on the precision in each of the methods used in individual TMDL elements and the needs of the stakeholder community. It is difficult to characterize the degree of accuracy associated with different linkage methods; however, this guidance provides a rough sense of the relative accuracy each method provides.

Settings where linkage accuracy is more important

Where relatively accurate methods are used throughout the TMDL, they might lend themselves to, and assist in, establishing clear linkages. Clear linkages may be particularly important for a TMDL where finality and certainty are sought—where the TMDL is supposed to be "right" on the first try. In addition, where sediment problems are very serious, watershed issues are contentious, or stakeholders disagree about sediment-related issues and potential solutions, more precise linkages between TMDL elements might be needed for several reasons. In many cases, TMDLs become contentious because the financial stakes for involved stakeholders are high. Clearer linkages can assist stakeholders in understanding why particular sediment sources and impacts need to be addressed, make the TMDL more defensible if challenged, and provide a more rigorous basis for future monitoring design.

Settings where linkage accuracy is less important

If each TMDL element is relatively crude, it might be enough to explain the theoretical linkage between elements and not expect direct quantitative linkages. This approach could be particularly appropriate in settings where the TMDL is to be done in phases and a strong commitment to adaptive management over time exists. Moreover, stakeholder expectations are an important consideration here. Where watershed issues are not highly controversial and the stakeholder community seems ready to take effective action, specific linkages might not need to be established in advance with a high degree of precision. In this type of situation, adequate linkages should be made to inform the design and implementation of follow-up "hypothesis-based" monitoring and adaptive management. Finally, precise linkages might be less important in watersheds where the problem is not very serious and where modest action would be adequate. Where qualitative approaches to linkage are used, the TMDL should document all assumptions, theories that provide the basis for linkage, expert and literature citations, and provisions for follow-up monitoring.

2. What is an appropriate method for linkage?

Many approaches to linking or synthesizing the elements of a TMDL are available. Some of these approaches were reviewed in the discussion of source analysis approaches. This section briefly reviews a range of possible approaches and discusses examples. For more detailed discussions of linkage principles and methods, see Washington Forest Practices Board (1994), Regional Ecosystem Office (1995), Reid (1996), and Dissmeyer (1994).

Potential Linkage Methods

Mathematical Linkages
Process Model Linkages
Empirical Linkages
Linkage by Inference
Index Linkages

Mathematical linkages

Linkages between numeric targets and source loadings can often be determined through quantitative analysis of the TMDL elements and underlying data used to develop these elements. A variety of straightforward arithmetic and statistical analyses are available. Where these approaches are used, it is recommended that analysts identify a theoretical basis for the relationship between indicators and the sources of concern. In addition, where these relationships are not well understood, it might be appropriate to frame the linkages as testable hypotheses to be further evaluated through follow-up monitoring and evaluation. In most cases, mathematical linkages provide moderately accurate results.

Direct arithmetic linkages can be drawn between numeric target and source analysis elements in some cases. For example, a linear association can be established between in-stream and upslope analysis (see Silver Creek, Arizona, example in inset box). Analysts should take care to examine the theoretical basis for assuming particular functional relationships between in-stream conditions and upslope sediment production measures. In some cases it is reasonable to assume linear functional relationships, whereas data transformations might be needed in other cases to establish meaningful functions. (See USEPA [1997b] for more information on evaluation of functional relationships through regression analysis.)

Linkage in Silver Creek, AZ, TMDL Study

In a pilot TMDL analysis for Silver Creek, sediment loading reduction targets were estimated through the following ratio:

$$\frac{\text{existing instream sediment concentration}}{\text{desired instream sediment concentration}} \sim \frac{\text{existing sediment loadings}}{\text{target sediment loadings}}$$

Sediment loading reduction targets were then derived by subtracting target loading levels from existing loading levels (Source: Limno Tech, 1993).

For TMDLs in which numeric targets include functional relationships (e.g., the slope of the TSS/flow regression curve in the Deep Creek, Montana, TMDL), it might be feasible to examine the distance between the regression curve derived for the study area and the comparable curve calculated for a reference stream to determine how much change is needed in sediment delivery, transport, or net sediment yield to attain the targets.

In-stream and upslope sediment analysis linkages can also be developed with more rigorous methods. Several studies have linked in-stream and upslope indicators through the use of statistical regression analysis. For example, a study in the Sierra Nevada range of California (McGurk and Fong, 1995) found a reasonably robust relationship between aquatic invertebrates and equivalent roaded acreage (ERA) measures, which helped to evaluate the utility of the ERA method and appropriate threshold levels.

In a study of northern California coastal streams (Knopp, 1993), a statistical link was drawn between watershed disturbance, as measured by a crude sediment budget analysis, and several in-stream sediment indicators, including geometric mean particle size, V*, and riffle-armor stability index, to evaluate the ability of in-stream metrics to discriminate between relatively disturbed and undisturbed watersheds (and associated historical sediment production). Other approaches are possible and should be considered in cases where relatively robust data sets are available and statistical analysis of these data sets can be undertaken. By examining the differences between conditions in the study area and in reference sites, it should be feasible to estimate needed load reductions.

Process model linkages

Mechanistic or process models may also be used to draw relatively accurate linkages between TMDL elements in many cases. For example, sediment budgeting methods that estimate net sediment discharge from a watershed could be used to identify the degree of change in sedimentation processes needed for those processes to mimic natural conditions. The sediment budgeting analysis in the South Fork Salmon River, Idaho, indicated that the river system was beginning to recover from large historical sediment inputs, but that the river lacked the hydraulic energy needed to move accumulated in-stream sediments out of the system. This finding led analysts to design a sediment input reduction strategy that would reduce sediment loading to the stream, thereby enabling the river to gradually remove excess in-stream sediments. By accounting for the different components of sediment movement through a system (erosion, upslope storage, delivery to streams, in-stream storage, transport, and net sediment discharge), these methods enable the analyst to quantitatively estimate load reduction needs and compare the effectiveness of alternative sediment management options.

In addition, process models that directly use sediment indicators can often provide a framework for linkage of in-stream endpoints based on sediment measures and sediment source and allocation analysis. Several of the more complex models discussed in the source analysis section (e.g., HSPF, SWRRBQ, EFDC, GSTARS, SWMM, and possibly AGNPS) might be capable of providing this framework.

Empirical linkages

A variety of empirical linkage approaches are possible. For example, in projects that use suspended sediment load as an target, it might be feasible to link source analysis, allocation, and numeric target elements by simply ensuring that the sum of expected loads from significant sources does not exceed the allowable load at a downstream compliance point, as calculated by a function of suspended sediment and flow data. This approach would also facilitate the identification of total allowable loads or total sediment load reductions needed. Significant uncertainty is likely to exist in each component of the empirical linkages and will vary depending on the quality of data sets.

Another empirical linkage approach is to use thresholds of concern for upland or in-stream indicators and an adaptive management approach to land management in the future that links exceedance of one or more thresholds with a management decision. For example, a TMDL could reference a management approach by stating that if a disturbance index or substrate composition indicator threshold were exceeded, specific actions would be taken (e.g., cease the activity or use more protective management practices) at specific times. If the case can be made that the adaptive response to exceeding a threshold is significantly more protective than the initial land use activity causing sedimentation, this approach could provide an adequately robust framework for TMDL linkage and eventual success (e.g., Louisiana-Pacific Corporation, 1996).

Linkage by inference

In some cases, indirect inferences of relationships between TMDL elements may suffice. For example, an in-stream analysis might show that relatively modest reductions (say, 10 to 20 percent) in sediment discharge are needed to attain established sediment targets. If the source analysis and allocation elements could be linked to show that very large reductions (e.g., 50 to 75 percent) in sediment inputs are expected to result from planned management and restoration actions, the rough comparison of the elements could be construed to infer the adequacy of the overall TMDL approach. A theoretical connection should be established or hypothesized based on expert judgment or literature references to support linkages made through indirect inferences. Such inferred linkages are likely to be quite crude, but they might be adequate in some situations.

Index linkages

There are a variety of approaches to combining physical and biological assessment tools to assist in linking TMDL elements. These methodologies provide a systematic framework for conducting and synthesizing biological, physical, and chemical measurements of habitat characteristics. Examples that have been used in settings where sediment contamination is a key concern include EPA's Rapid Bioassessment Protocols (USEPA, 1989), the Fish and Wildlife Service's Index of Biotic Integrity (McMahon, 1983), and various habitat typing methods (e.g., California Department of Fish and Game, 1994). In some cases, these methods provide guidance on determining whether existing conditions are "good enough" or whether habitat is impaired (e.g., McMahon, 1983).

These methods are most useful in linking disparate numeric indicators to create composite rankings of habitat quality. The methods also have potential for establishing target conditions for multiple indicator projects where aquatic habitat is impaired by sediments (and potentially other stressors). These methods do not directly lend themselves to estimation of total assimilative capacity, but could conceivably be used to infer estimates of sediment reductions needed.

Linking multiple indicators or multiple source assessment methods

As discussed in the previous chapters, multiple indicators and/or multiple source analysis methods could be needed to ensure that the analysis of complicated watershed settings adequately accounts for complex in-stream sediment impacts and the complex watershed processes that drive sediment loading. It is rarely necessary to link all indicators in a seamless, logical fashion. Likewise, not all indicators need to be linked with the entire source analysis and associated allocations. The objective should be to define adequate linkages to provide logical coherence to the project without straining scientific credibility or burdening an already complicated analysis project. Several linkage approaches might be adequate for this purpose.

One strategy is to link like indicators with like source analysis elements (e.g., bank erosion targets linked with bank erosion measures and controls in the Deep Creek, Montana, TMDL). A second strategy is to first synthesize estimates of sediment loads from different sources that were developed with different methods (e.g., through a sediment budget), then link the overall sediment loading estimate with the in-stream indicators for purposes of reduction and allocation planning (e.g., Sycamore Creek, Michigan).

Another approach is to use watershed analysis methods as a linkage framework (e.g., Washington's TFW approach and the federal watershed analysis procedures). These methods hold substantial promise as integrating mechanisms where they are being implemented, although linkages between aquatic resource impacts and land management patterns that contribute to those impacts have rarely been established through rigorous methods.

3. What is the linkage and what is the resulting estimated loading capacity or needed load reduction?

The linkage analysis should show how numeric targets and source analysis results relate to each other and how they combine to yield estimates of sediment assimilative capacity or needed sediment load reductions. An example linkage analysis is provided below. The example illustrates how professional judgment combined with simple arithmetic comparisons of existing and target conditions can be used to link numeric targets and source analysis results to estimate assimilative capacity. This estimate provides the basis for the allocation of loads or load reduction plans to be devised in the next TMDL step.

In this example, the target values are based on conditions at a reference site. The indicators chosen are percent fines, geometric median particle size, and average pool depth; the target values for the indicators are established at the values of the reference site.

A sediment budget for the impaired watershed shows that the estimated annual sediment loading is 80 tons/mi^2. To determine a rough estimate of the needed load reductions, the existing conditions can be compared to the target conditions. The percentage of fine sediment is 60 percent greater, the median particle size is 30 percent smaller, and the average pool depth is 30 percent shallower. The average departure of existing conditions from target conditions is therefore 40 percent ((60% + 30% + 30%)/3). Based on expert interpretation and assuming that linear comparisons are valid, one approach to load reduction needs would be to specify that existing loads should be reduced by an equivalent percentage, or that loads should be reduced by 40 percent to approximately 48 tons/mi^2.

Indicator	Target (Reference) Level*	Existing Condition*
% fine sediment < 0.85 mm	11%	18%
Median particle size	20 mm	15 mm
Average pool depth	2 m	1.5 m

* A range of values for each indicator and target is likely in actual settings; single values are used here to simplify the presentation.

Recommendations for Linkage of Water Quality Targets and Sources

- Use all available and relevant data; ideally, the linkage will be supported by monitoring data, allowing the analyst to associate waterbody responses with flow and loading conditions.
- Selection of an appropriate technique must be made on a site-specific basis and should consider the nature of the indicator to be evaluated, hydraulic characteristics of the waterbody, user requirements, relevant temporal and spatial representation needs, and stakeholder interests.
- When selecting a technique to establish a relationship between sources and water quality response, usually, the simplest technique that adequately addresses all relevant factors should be used.

RECOMMENDED READING

(Note that the full list of references for this chapter is included at the end of the document.)

Dissmeyer, G.E. 1994. *Evaluating the effectiveness of forestry best management practices in meeting water quality goals or standards.* USFS Miscellaneous Publication 1520. U.S. Department of Agriculture, U.S. Forest Service, Washington, DC.

Regional Ecosystem Office. 1995. *Ecosystem analysis at the watershed scale.* Version 2.2. U.S. Government Printing Office: 1995-689-120/21215 Regional Ecosystem Office, Portland, OR.

USEPA. 1997c. *Compendium of tools for watershed assessment and TMDL development.* EPA 841-B-97-006. U.S. Environmental Protection Agency, Washington, DC. <http://www.epa.gov/owow/tmdl/techsupp.html>

Washington Forest Practices Board. 1994. *Standard methodology for conducting watershed analysis under chapter 222-22 WAC.* Version 2.1, November 1994. Washington Forest Practices Board, Olympia, WA.

Allocations

Objective: Using total assimilative capacity developed in the linkage component, develop recommendations for the allocation of loads among the various point and nonpoint sources, while accounting for uncertainties in the analyses (MOS) and, in some cases, a reserve for future sources.

Procedure: Determine the allocations based on identification of the acceptable loading (loading capacity), the margin of safety, and the estimated loads from significant sources. The available load is then allocated among the various sources.

OVERVIEW

A TMDL is legally defined as the sum of wasteload allocations to point sources, load allocations to nonpoint and natural background sources, and a margin of safety considering seasonal variation (40 CFR 130.2). Although there are many ways to express TMDLs, the concept of allocation is central to the TMDL process because it reinforces the importance of identifying what sources need to be addressed to attain water quality standards. Therefore, sediment TMDLs should clearly provide for allocations by source of maximum allowable loads, needed load reductions, or, in some cases, source control actions.[1]

Pollutant allocations (e.g., maximum allowable loads or needed load reductions per unit of time) are strongly recommended where feasible. The allocations provide a framework for identifying specific source reduction levels. In most TMDLs, the allocation element does not identify specific implementation measures; rather, those measures are identified in an implementation plan that is legally distinct from the TMDL. The implementation plan is often developed concurrently with the TMDL and sometimes as a follow-up activity. It is usually advantageous to develop the implementation plan at the same time as the TMDL to

- Make efficient use of assessment and planning resources and the time of participants.
- Increase the likelihood that actions needed to implement the TMDL will actually be carried out.
- Improve the analytical basis for concluding that allocations will be effective in meeting TMDL targets.

Key Questions to Consider for Allocations

1. What key factors affect selection of allocation method(s)?
2. What is an appropriate allocation method?
3. How are allocations described in the TMDL document?
4. What changes does the proposed rule speak to?

Allocations should be accompanied by adequate documentation to provide reasonable assurance that the changes in sediment dynamics in the watershed (reductions, increases, or redistributions) needed to implement the TMDL allocations will be implemented and will result in the attainment of water quality standards. To provide the reasonable assurance needed, the TMDL submittal usually includes an analysis showing that the sum of allocations does not exceed the waterbody's assimilative capacity for sediment as identified in the linkage step. In addition, some analysis showing the feasibility of implementing proposed allocations should be provided if possible. This section reviews key factors to consider in the allocation process and discusses several allocation approaches.

KEY QUESTIONS TO CONSIDER FOR ALLOCATIONS

1. What key factors affect selection of allocation method(s)?

The following factors usually influence the selection of an allocation approach.

Types of sources and management options

Allocations should usually be organized along the same lines as the source analysis and linkage elements (e.g., by source category, tributary area, land parcel, or possibly a combination of these). Following the same

[1] Although some sediment TMDLs might determine a need to increase sediment loading to address an impairment, this analysis focuses on the more likely scenario that sediment *reductions* will be needed to address the designated use problem(s).

approach in the allocation step usually eases the task of demonstrating that the sum of allocated reductions or management actions offers reasonable assurance of success, defined in this case as eventual attainment of numeric targets. It might not be necessary to devise allocations for each source category, tributary, or land area if action taken to address a subset of sources shows clear likelihood of success.

Analysts should also consider how sediment sources are expected to be controlled and tailor allocations accordingly. For example, in a case where erosion from roads is the key source of concern, an allocation could be expressed in different ways depending on how such erosion is to be controlled. If the focus is on prevention of road-related erosion through replacement of failing culverts, the allocation could be done in terms of total tons of avoided sediment loading to be realized through culvert management. Alternatively, if road-related erosion is to be controlled by reducing the miles of active roads per square mile, the allocation could be expressed in terms of percent reductions in sediment loading by tributary watersheds.

In another example, sediment runoff from fields under multiple-stage crop rotation varies depending on which crop is planted at any one time. TMDL allocations should therefore be designed to ensure that sediment production associated with the maximum sediment production stage of the rotation does not exceed acceptable levels (Davenport, 1983).

Equity issues

Allocations entail distribution of sediment control needs or expectations among different point and nonpoint sources. Because costs of controlling different sources can vary substantially, the allocation analysis should consider whether the allocations create reasonably fair distributions of control costs. Analysts might want to develop cost/benefit analyses of potential control actions to assist in fairly distributing control costs.

Typically, responsible parties are more likely to carry out actions needed to implement TMDLs if they feel their share of the sediment control burden is fair. Therefore, analysts are advised to consult with affected stakeholders during the development of allocations. Many methods for developing allocations that result in equitable control burdens are available. Refer to USEPA (1991a, 1991b, 1999) for additional guidance on allocation development.

Variability in loads and impacts

Allocations should be developed with an understanding of spatial and temporal variability in sediment loading and designated use impacts. The allocations should be established at levels that ensure that designated uses are protected at critical time periods and in key locations (e.g., allowance of zero anthropogenic sediment discharge to stream reaches containing spawning grounds during spawning periods).

Margin of safety issues

As discussed in the introduction, the margin of safety (MOS) required in each TMDL can be addressed implicitly through inclusion of conservative analytical assumptions or methods or explicitly through reservation of a portion of the available loading to account for uncertainty. The explicit MOS approach is usually addressed during the allocation phase. In cases where the TMDL provides the required MOS through implicit analysis assumptions, the allocation section should indicate that this approach makes the need for an explicit reservation of loading capacity as an MOS unnecessary. Tha allocation section should also identify the conservative assumptions used in the analysis and explain how they adequately account for uncertainties. Where an explicit allocation is reserved as an MOS, the analysis should discuss why this reservation is adequate to account for uncertainty present in the TMDL.

Future Growth

Recognizing that in some watersheds there will be growth that results in increased loadings, some TMDLs may allocate a portion of the loading capacity for this growth. In this situation, the State will make the specific allocation to a facility in the future when the loading increases occur. Current guidance clarifies that any reserved allocation for future growth cannot also be used as a margin of safety.

On August 23, 1999, EPA published proposed rules that, when finalized, will require that an approvable TMDL must include an allowance for future growth which accounts for reasonably foreseeable increases in pollutant loads, or otherwise state that there is no capacity for growth. States, Territories, and authorized Tribes will need to include future growth in their allocation strategy and carefully document their decision-making process. The TMDL documentation should clearly explain the implications of the growth allocation decision on new and existing point and nonpoint sources of a pollutant. It should also explain what other local planning processes may be affected.

Needs for stakeholder involvement and public outreach

Since the reason for establishing sediment TMDLs is to set the stage for productive action, TMDL allocations that clearly define needed load reductions are more likely to be understood and supported by stakeholders.

If allocations are vague and the roles of agencies, landowners, and other stakeholders are not clear, misunderstandings might arise later and project effectiveness could suffer. The best ways to ensure stakeholders' support for allocations are to involve them in allocation development early, to fully document the basis for each allocation, and to show how the allocations "add up" to provide an effective overall plan.

Implementation and reasonable assurance issues

Feasible allocations should be supported by information or analysis providing reasonable assurance that their implementation will occur and that TMDL targets will be met. Where point source discharges are concerned, it might be enough to cite the regulatory basis for point source permitting and to explain that a permit will be required. With nonpoint sources, it is sometimes difficult to demonstrate that a set of management measures or restoration projects can be developed to achieve the projected load reductions (EPA 1991a). (EPA's August 1997 policy memorandum [USEPA, 1997a] discusses implementation issues for waters impaired solely or primarily by nonpoint sources.) The relationship between land management activities and sediment processes is complex and not easy to quantify through simple measures. Therefore, creativity and flexibility might be needed to build a record supporting the feasibility and adequacy of proposed allocations. In general, the greater the demand for specific assurances that allocations are feasible and that associated actions will be implemented, the more likely it will be that specific quantitative allocations linking sediment loading caps, reductions, or other source control targets need to be associated with specific management actions. In some projects, reasonable assurance that the load reduction will be achieved might be related to stakeholders agreeing on the watershed's problems and the implementation of appropriate solutions.

Many methods can be used to document the basis for allocations and to assess their expected feasibility. Documentation will be most effective if it explains (1) why the allocations, when attained, will result in sediment loads that do not exceed waterbody assimilative capacity as identified in the linkage element and (2) how the allocations will be implemented.

Documentation may be based on modeling results or other rigorous quantitative analysis showing why a certain allocation meshes with total allowable loads or needed sediment reductions. However, less sophisticated approaches might also work in some settings. For example, in a case where a sediment loading percentage reduction target needs to be met through BMP implementation, the analyst could show literature values regarding effectiveness found in BMP guidance documents. Good sources of information about sediment BMPs and their effectiveness include EPA's management measures guidance (USEPA, 1993), USDA Forest Service conservation handbooks (e.g., USDA Forest Service, 1988), NRCS Field Office technical guides, and state BMP handbooks (e.g., Platts, 1990). In addition, reference could be made to results from similar projects. If a similar project was effective, analysts might have a sound basis for suggesting that the same control or restoration approaches would work. Where a strong adaptive management component is planned for the project, less rigorous documentation of the expected effectiveness of the allocations could be adequate.

In cases where implementation of actions associated with allocations is expected to occur under the auspices of a regulatory mechanism (e.g., timber harvest plans, grazing allotments, construction permit, or storm water permit), it might be helpful to describe how the actions are factored into the regulatory framework. Such a description would help bolster the analysis supporting the allocations.

2. What is an appropriate allocation method?

Many methods are available to establish effective allocations. The first step in establishing allocations is to determine the segments and sources that require allocations to achieve water quality standards. Sources where allocations are needed might be evident based on screening-level analyses. However, the actual establishment of allocations will depend on many factors, such as decisions about whether reductions should be spread out across all sources or applied to a few targeted sources. Each TMDL will likely have its own criteria for making these decisions (e.g., magnitude of impact, degree of management control now in place, feasibility, probability of success, costs). For sediment TMDLs, analysts should consider the following options as a starting point for expressing allocations:

- Maximum allowable loads
- Percentage reduction targets
- Performance-based actions or practices

However, other allocation options are available and should be explored.

Maximum allowable loads

Specific allocation of maximum allowable mass loads to specific source categories, tributaries, or channel types or from specific parcels, erosion process categories (e.g., landslides), or distinct geologic types are the allocation approaches most commonly used in sediment TMDLs (e.g., Garcia River, California, Simpson Timberlands, Washington [draft]). Specific allocations of loading caps or other thresholds offer relatively precise targets and a clear basis for monitoring. Given the variability of sediment dynamics in many systems, it might not be feasible or wise to set allocations in this manner because they might not reflect the expected imprecision in the target and source analysis components of some TMDLs. If these targets are framed as preliminary hypotheses to be tested and adjusted if necessary over time, they might be more defensible and will likely receive a more positive response from stakeholders. Another approach to addressing expected variability in loadings over time is to set allocations for relatively long time steps (e.g., average annual sediment load per square mile) expressed as a multiyear rolling average (e.g., 10-year rolling average for Redwood Creek, California, TMDL). This approach recognizes that annual or seasonal loads will vary substantially in response to different precipitation patterns.

The disadvantage is that this approach creates a significant lag time between the implementation of TMDL-related sediment controls and the review of the effectiveness of those controls. Some TMDLs address this disadvantage by incorporating sensitive monitoring triggers as numeric targets. For example, the Newport Bay/San Diego Creek TMDLs include numeric targets for maintenance of wetland habitat types that are sensitive to change due to sediment loading. If the acreage of any particular habitat type in a key wildlife refuge changes more than 1 percent, the TMDL implementation plan requires the state to immediately review the TMDL for potential revisions. It might also be possible to use turbidity or suspended sediment targets to provide more sensitive numeric targets. (Targets of this type are discussed in the numeric targets section in Chapter 4.)

Percentage reduction targets

As an alternative to maximum allowable loads, allocations can be expressed in terms of percentage reductions in sediment loading allocated among sources (e.g., Deep Creek, Montana). Percent reduction targets enable the analyst to account for the uncertainties and variabilities in the analysis of dynamic watershed settings while providing a quantitative basis for allocations and subsequent monitoring. The simplicity of this approach is appealing in many settings. However, it might be more difficult to measure attainment of percent reduction targets because this approach might require more complicated monitoring than that used for some other methods. For this approach to work, estimates of baseline sediment loading conditions by source are needed to determine the appropriate percentage reductions needed. Relatively simple baseline estimates might be adequate for this purpose.

Allocations based on performance of actions or practices

In some cases, allocations can be expressed in terms of project performance expectations (e.g., tons of sedimentation avoided due to road improvements) associated with specific projects or management practices, which, as a group, "add up" to meet overall sediment management goals (e.g., South Fork Salmon River, Idaho, and Chalk Creek, Utah [USEPA, 1996c)]. This allocation approach usually entails estimating the erosion reduced or avoided as a result of implementing specific practices. Project performance expectations offer tangible connections to specific management or restoration actions in specific places. This approach facilitates the identification of specific action based on allocations and the monitoring of project effectiveness. Its main drawback is that it is often difficult to show how the projected sum of avoided sedimentation from multiple projects adds up to reasonable assurance that overall source reduction or in-stream targets can be attained. This approach might work best where the expected magnitude of sediment control actions significantly exceeds the needed sediment reductions.

A related allocation approach identifies in detail the practices to be implemented to address specific sources of concern. Provided with the action plan is a rationale that shows why the set of identified actions is expected to be adequate to attain the total sediment load reductions needed (as identified during the linkage phase of the TMDL). This rationale could be based on the professional judgment of resource experts involved in TMDL and implementation planning; modeling results; literature and agency guidance that provide estimates of BMP and restoration effectiveness in sediment control; and experience with similar sediment control projects.

Because this approach lacks the direct allocation of loads or load reductions and instead shows how allocation of actions is adequate to attain necessary load reductions, the approach is most appropriate under the following circumstances:

- Stakeholders strongly support the actions to be taken, and there is reasonable assurance that the actions will occur (e.g., landowner and funding commitments are in place, actions are required by permits or ordinances).
- Adequate information concerning BMP or restoration project effectiveness is available to support an argument that the actions will be adequate to attain needed load reductions.
- Follow-up monitoring is included as part of the TMDL and implementation plan.

3. How are allocations described in the TMDL document?

Individual allocations by source should be identified, along with any allocation characteristics that account for variability in source inputs or in-stream impacts (e.g., seasonal variations in allowed loads). The rationale supporting the allocations should be described in adequate detail to show that the allocations will result in attainment of water quality standards and that their implementation is feasible. Uncertainties in the analysis should also be discussed. Where implementation planning is done concurrently with allocation, it might be appropriate for the allocation section to reference the implementation plan to further explain the intended approaches for addressing sources. In most cases, however, the document should clearly distinguish the allocations from the implementation actions.

4. What changes does the proposed rule speak to?

On August 23, 1999, EPA published proposed rules that specify that approvable TMDLs must include at a minimum ten elements. Within the allocation step, an approvable TMDL will need to include the following information:

1. Wasteload allocations to each industrial and municipal point source permitted under §402 of the Clean Water Act discharging the pollutant for which the TMDL is being established; wasteload allocations for storm water, combined sewer overflows, abandoned mines, combined animal feeding operations, or any other discharges subject to a general permit may be allocated to categories of sources, subcategories of sources or individual sources; pollutant loads that do not need to be allocated to attain or maintain water quality standards may be included within a category of sources, subcategory of sources or considered as part of background loads; and supporting technical analyses demonstrating that wasteload

allocations when implemented, will attain and maintain water quality standards;

2. Load allocations to nonpoint sources of a pollutant, including atmospheric deposition or natural background sources. If possible, a separate load allocation must be allocated to each source of natural background or atmospheric deposition; load allocations may be allocated to categories of sources, subcategories of sources or individual sources. Pollutant loads that do not need to be allocated may be included within a category of sources, subcategory of sources or considered as part of the background load. Supporting technical analyses must demonstrate that load allocations, when implemented, will attain and maintain water quality standards;

3. A margin of safety expressed as unallocated assimilative capacity or conservative analytical assumptions used in establishing the TMDL; e.g., derivation of numeric targets, modeling assumptions, or effectiveness of proposed management actions which ensures attainment and maintenance of water quality standards for the allocated pollutant;

4. Consideration of seasonal variation and high and low flow conditions such that water quality standards for the allocated pollutant will be met during all design environmental conditions;

5. An allowance for future growth which accounts for reasonably foreseeable increases in pollutant loads; and

6. An implementation plan, which may be developed for one or a group of TMDLs.

Minimum Elements of an Approvable Implementation Plan

Whether an implementation plan is for one TMDL or a group of TMDLs, it must include at a minimum the following eight elements:

- *Implementation actions/management measures:* a description of the implementation actions and/or management measures required to implement the allocations contained in the TMDL, along with a a description of the effectiveness of these actions and/or measures in achieving the required pollutant loads or reductions.

- *Time line:* a description of when activities necessary to implement the TMDL will occur. It must include a schedule for revising NPDES permits to be consistent with the TMDL. The schedule must also include when best management practices and/or controls will be implemented for source categories, subcategories and individual sources. Interim milestones to judge progress are also required.

- *Reasonable assurances:* reasonable assurance that the implementation activities will occur. Reasonable assurance means a high degree of confidence that wasteload allocations and /or load allocations in TMDLs will be implemented by Federal, State or local authorities and /or voluntary action. For point sources, reasonable assurance means that NPDES permits (including coverage under applicable general NPDES permits) will be consistent with any applicable wasteload allocation contained in the TMDL. For nonpoint sources, reasonable assurance means that nonpoint source controls are specific to the pollutant of concern, implemented according to an expeditious schedule and supported by reliable delivery mechanisms and adequate funding.

- *Legal or regulatory controls:* a description of the legal authorities under which implementation will occur (as defined in 40 CFR 130.2(p)). These authorities include, for example, NPDES, Section 401 certification, Federal Land Policy and Management programs, legal requirements associated with financial assistance agreements under the Farm Bills enacted by Congress and a broad variety of enforceable State, Territorial, and authorized Tribal laws to control nonpoint source pollution.

- *Time required to attain water quality standards:* an estimate of the time required to attain water quality. The estimates of the time required to attain and maintain water quality standards must be specific to the source category, subcategory or individual source and tied to the pollutant for which the TMDL is being established. It must also be consistent with the geographic scale of the TMDL, including the implementation actions.

- *Monitoring plan:* a monitoring or modeling plan designed to determine the effectiveness of the implementation actions and to help determine whether allocations are met. The monitoring or modeling plan must be designed to describe whether allocations are sufficient to attain water quality standards and how it will be determined whether implementation actions, including interim milestones, are occurring as planned. The monitoring approach must also contain an approach for assessing the effectiveness of best management practices and control actions for nonpoint sources.

- *Milestones for attaining water quality standards:* a description of milestones that will be used to measure progress in attaining water quality standards. The milestones must reflect the pollutant for which the TMDL is being established and be consistent with the geographic scale of the TMDL, including the implementation actions. The monitoring plan must contain incremental, measurable milestones consistent with the specific implementation action and the time frames for implementing those actions.

- *TMDL revision procedures:* a description of when TMDLs must be revised. EPA expects that the monitoring plan would describe when failure to meet specific milestones for implementing actions or interim milestones for attaining water quality standards will trigger a revision of the TMDL.

RECOMMENDATIONS FOR ALLOCATIONS

- Allocations should be accompanied by adequate documentation to provide reasonable assurance that the suggested changes will result in attainment of water quality standards.
- It might be helpful to organize allocations along the same lines as source assessment and linkage (e.g., by source category or land parcel).
- Involve affected stakeholders in developing allocations.
- Clarify whether the margin of safety is implicit or explicit and explain the rationale behind the decision.

RECOMMENDED READING

(Note that the full list of references for this chapter is included at the end of the document.)

USEPA. 1991a. *Guidance for water quality-based decisions: The TMDL process.* EPA 440/4-91-001. U.S. Environmental Protection Agency, Washington, DC. <http://www.epa.gov/owow/tmdl/policy.html>

USEPA. 1991b. *Technical support document for water quality-based toxics control.* EPA/505/2-90-001. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1993. *Guidance specifying management measures for sources of nonpoint pollution in coastal waters.* EPA 840-B-92-002. U.S. Environmental Protection Agency, Washington, DC.

USEPA 1999. *Draft guidance for water quality-based decisions: The TMDL process (second edition).* EPA 841-D-99-001. U.S. Environmental Protection Agency, Washington, DC. <http://www.epa.gov/owow/tmdl/proprule.html>

Follow-up Monitoring and Evaluation

Objective: Define the monitoring and evaluation plan to validate TMDL elements, assess the adequacy of control actions to implement the TMDL, and provide a basis for reviewing and revising TMDL elements or control actions in the future.

Procedure: Identify the key questions that a monitoring plan needs to address and evaluate monitoring options and the feasibility of implementing a monitoring program. Describe the specific monitoring plan, including timing and location of monitoring activities, parties responsible for conducting monitoring, and quality assurance/quality control procedures. Describe the schedule for reviewing monitoring results to consider the need for TMDL or action plan revisions, and discuss the adaptive management approach to be taken. The monitoring component of a TMDL results in a description of monitoring and adaptive management plan objectives, methods, schedules, and responsible parties.

OVERVIEW

Sediment-related impacts on designated uses are often difficult to characterize. For this reason, sediment TMDLs are likely to have significant uncertainty associated with selection of numeric targets and estimates of source loadings and waterbody assimilative capacity. Recognizing the inherent uncertainty, EPA has encouraged the development of TMDLs using available information and data with the expectation that a monitoring plan will be developed and submitted with the TMDL (USEPA, 1991a, 1999). This approach allows proceeding with source controls while additional monitoring data are collected to provide a basis for reviewing and revising the TMDL. This "adaptive management" approach enables stakeholders to move forward with resource protection based on reasonably rigorous planning and assessment.

The monitoring and adaptive management plan is a central element of TMDLs and is highly advisable for all sediment TMDLs. This chapter discusses key factors to be considered in developing the monitoring plan and suggests additional sources of guidance on monitoring plan development.

Many types of monitoring activities should be considered when developing the monitoring plan (MacDonald et al., 1991). The types of monitoring programs and their definitions as used in this document are from monitoring guidelines developed by MacDonald et al. (1991). They include

- Baseline monitoring
- Implementation monitoring
- Effectiveness monitoring
- Trend monitoring
- Validation monitoring

Baseline monitoring characterizes existing conditions and provides a basis for future comparisons. Baseline monitoring should also include information on source controls in place in the watershed, including the types of controls present, where they are located, and general information on their past effectiveness in controlling erosion. This type of monitoring is not always necessary for the monitoring plan. Usually, some baseline data that were considered during TMDL development already exist.

Implementation monitoring ensures that identified management actions (such as specific BMPs or resource restoration or enhancement projects) are undertaken. Implementation monitoring is often cited as the most cost-effective of the monitoring types because it provides information on whether BMPs are being installed or implemented as intended. This type of monitoring will not provide a link to in-stream water quality.

Effectiveness monitoring is used to assess whether the source controls had the desired effect. Specific projects that potentially affect water quality conditions should be monitored to determine their immediate on-site effects.

Trend monitoring is used to assess changes in conditions over time relative to the baseline and identified target values. Trend monitoring is critical, assuming the other elements of the TMDL are appropriately developed. It addresses the changing conditions in the waterbody that result from TMDL-specific activities, as well as other land management activities over time. This is the most critical component of the monitoring program since it also documents progress toward achieving the desired water quality conditions.

Validation monitoring is used to validate source analysis and linkage methods. This type of monitoring provides a different data set that can be used to provide an unbiased evaluation of the overall performance of methods or models used in the analysis.

A monitoring program includes the following elements, which should be addressed in the monitoring plan:

- The specifications for the location and timing of monitoring.
- The types of monitoring techniques to be used.
- The standard operating procedures and appropriate quality assurance protocols.
- Procedures for the storage of collected information and for internal and public access to such information.
- Analytical techniques and objectives for the interpretation and analysis of information gathered.
- A process for refining and modifying the monitoring design in response to changing objectives and improved information.
- A designated laboratory with sufficient capacity and appropriate levels of certification.

It is not possible to provide details on the factors that should be considered in development of monitoring plans for all environments in this document. Instead, this document provides a review of general monitoring considerations and factors that might help to optimize data collection and interpretation in the context of TMDL development.

Key Questions to Consider for Follow-up Monitoring and Evaluation

1. What key factors influence monitoring plan design?
2. What are some of the potential monitoring approaches for sediment TMDLs?
3. What is included in an appropriate monitoring plan?
4. What is an appropriate adaptive management plan, including review and revision schedule?
5. What constitutes an adequate monitoring plan?

KEY QUESTIONS TO CONSIDER FOR FOLLOW-UP MONITORING AND EVALUATION

1. What key factors influence monitoring plan design?

Many factors influence the necessary rigor of a monitoring plan. For example, in watersheds where limited data are available for TMDL development, a more robust monitoring plan that outlines the steps to be taken to refine problem identification or confirmation might be necessary. In watersheds where the problem is better understood and source controls are in place, it might be more desirable for the monitoring plan to focus on monitoring source control implementation. Some of the key factors that influence the development of a monitoring plan include the following:

- What specific TMDL elements need evaluation?
- How can tracking of implementation of source controls be included in the monitoring plan?
- How can stakeholder involvement and goals be included?
- How can existing monitoring activities, resources, and capabilities be fully utilized?

What specific TMDL elements need evaluation?

TMDL problem identification, indicators and numeric targets, source estimates, and allocations might need reevaluation to determine whether they are accurate and effective. The monitoring plan should define specific questions to be answered about these components through the collection of monitoring information. The following factors/questions should be considered when determining on which components additional or new monitoring should be focused:

- Are the selected indicators and numeric targets capable of detecting designated use impacts and responses to control actions?
- What is the level of confidence in the characterization of baseline or background conditions?
- Were the data used to establish the numeric targets of sufficient quality to reasonably represent the appropriate desired conditions for designated uses of concern? Was uncertainty in the data within an acceptable range for the type of data?

- Was the source assessment comprehensive or are other sources suspected? Have sources been accurately estimated?
- Was the linkage between sources and in-stream impacts accurately characterized? Did the characterization rely heavily on screening-level analyses due to a lack of data? Would additional data provide any significant improvements to the analyses?
- Were the erosion and hydrologic processes that affect sediment production or impacts on designated uses accurately characterized?
- Where reference sites were used to help determine TMDL targets and load reduction needs, were reference site conditions accurately characterized? Would the analysis benefit from comparison to additional reference sites or from additional data collected from reference sites?

How can tracking of implementation of source controls be included in the monitoring plan?

It is often important to determine whether actions identified in the implementation plan were actually carried out (implementation monitoring) and whether these actions were effective in reaching the desired condition as outlined in the TMDL (effectiveness monitoring).

Specific questions to be considered when developing the monitoring plan include the following:

- What types of implementation problems are expected? Will specific landowners require special attention (e.g., landowners not party to the TMDL) or technical support?
- How can implementation monitoring be conducted in large watersheds?
- How will the implementation monitoring results be assessed and used in revising the TMDL?
- Will the implementation monitoring include any assessment of BMP effectiveness?

How can stakeholder involvement and goals be included?

Watershed stakeholders often participate in follow-up monitoring, and their interests, in addition to TMDL analysis, should be considered in devising monitoring plans. Monitoring plans should address the following:

- What stakeholder/volunteer groups are willing to participate in monitoring efforts?
- Where are likely locations for stakeholder/volunteer monitoring efforts?
- What types of data are amenable to collection by stakeholders or volunteers?
- How will data from stakeholders or volunteers be used in the TMDL revision?

How can existing monitoring activities, resources, and capabilities be fully utilized?

Analysts should identify existing and planned monitoring activities in an effort to address TMDL monitoring needs in concert with other efforts, particularly where a long-term monitoring program is envisioned, the study area is large, or water quality agency monitoring resources are limited. Staff capabilities and training should also be considered to ensure that monitoring plans are feasible. Factors to consider include the following:

- What data collection efforts are ongoing in the watershed? What kinds of data have been collected and what methods have been used?
- What other types of programs or studies are ongoing or planned in the watershed that were not identified in the original TMDL analysis? Will data collected

Characteristics of Effective Monitoring Plan

- Quantifiable approach. Results must be discernible over time so that they can be compared to previous or reference conditions.
- Appropriate in scale and application, and relevant to designated or existing uses and the TMDL methods.
- Adequately precise, reproducible by independent investigators, and consistent with scientific understanding of the problems and solutions.
- Able to distinguish among many different factors/sources (e.g., roads, mass wasting, agricultural practices, urban runoff, in-stream historical loads).
- Understandable to the public and supported by stakeholders.
- Feasible and cost-effective.
- Anticipatory of potential future conditions and climatic influences.
- Minimally disruptive to the designated uses during data collection.
- Conductive to reaching and sustaining conditions that support the designated or existing use.

by the programs or studies be of any use in a TMDL revision? Does the potential exist for pooling data collection and analysis resources?
- Were the data used in the original TMDL analysis? If not, why were the data omitted?
- Are known volunteer monitoring groups active in the watershed? In the region?

In addition to the factors presented above, many other practical considerations influence the design and development of a monitoring plan. Practical constraints include problems with access to monitoring sites due to landowner restrictions, physical barriers (e.g., topography), seasonal weather concerns, and concerns about indirect impacts of monitoring on habitat. Other factors influencing the design of monitoring plans and different types of monitoring of interest for TMDLs are discussed in detail in MacDonald et al. (1991).

2. What are some of the potential monitoring approaches for sediment TMDLs?

The protocol chapters concerning numeric targets, source analysis, and linkage discuss several analysis approaches that could provide the basis for monitoring parameter selection. Potential monitoring parameters are discussed in detail in MacDonald et al. (1991), Reid and Dunne (1996), and other monitoring texts. Approaches that might prove useful for TMDL and implementation plan monitoring include, but are not limited to, the following areas:

- Monitoring of channel condition and bed material to assess changes in channel structure and substrate composition.
- Aerial photography to assess changes in channel structure and erosion sources.
- Suspended load, bedload, and flow data to assess changes in sediment concentrations and mass loads.
- Biological indicators (e.g., invertebrates, fish populations, spawning rates, redd counts).
- Riparian and streambank indicators (e.g., woody debris, vegetation, erosion features).
- Hillslope erosion features (e.g., mass wasting features, gullies).
- Drainage features (e.g., reservoir, settlement basin, and drainage channel sediment levels).
- Calibrated models that can be used to simulate the implementation of controls. This approach can provide an interim evaluation of the potential effectiveness of different implementation approaches and the adequacy of different TMDL elements.

3. What is included in an appropriate monitoring plan?

The first step in developing an appropriate monitoring and adaptive management plan is to clearly identify the goals of the monitoring program. It might be possible to accomplish several of these monitoring goals simultaneously. For example, the primary need in most TMDLs will be to document progress toward achieving the numeric targets. During this process, the additional information collected might lead to a better understanding of the processes, suggesting a revision to the source analysis that would better pinpoint the sediment problem and lead to faster attainment of water quality improvements, or it might be that a particular restoration or enhancement project did not produce the desired effects and some changes to it should be undertaken.

Other guidelines for developing a monitoring plan include the following:

- Address the relationships between the monitoring plan and the TMDL's numeric targets, source analysis, linkages, and allocations, as well as the implementation plan.
- Articulate specific questions to be answered in the form of monitoring hypotheses, and explain how the monitoring program will answer those questions.
- Explain any assumptions being made.
- Discuss the likely effects of episodic events.
- The design can be delineated by source type, by geographical area, and/or by ownership parcel.
- Describe the monitoring methods to be used and provide the rationale for selection of these methods.
- Define monitoring locations and frequencies, and list who will be responsible for conducting the monitoring.
- Develop an appropriate Quality Assurance Project Plan. Detail sampling methods, selection of sites, and analysis methods consistent with accepted quality assurance/quality control practices. Have the monitoring plan peer-reviewed if possible. (For more information, refer to USEPA, 1994a, 1994b.)

4. What is an appropriate adaptive management plan, including review and revision schedule?

The plan should contain a section addressing the adaptive management component. This section should discuss when and how the TMDL will be reviewed. If possible, the plan should describe criteria that will guide TMDL review and revision. For example, the plan could identify expected levels of progress toward meeting TMDL numeric targets at the time of the initial review, stated in terms of interim numeric targets or interim load reduction expectations. In addition, the plan could identify "red flag" thresholds for key indicators that would signal fundamental threats to designated or existing uses and perhaps trigger a more in-depth review of the TMDL and implementation plan components. The adaptive management plan can also contain provisions for modifying the monitoring plan.

The adaptive management component does not need to schedule every conceivable TMDL review; it should be adequate to indicate the estimated frequency of review and identify a specific date for the initial review. It would be difficult to reliably forecast how often TMDL reviews will be needed, especially where problems might take several decades (or longer) to remediate.

5. What constitutes an adequate monitoring plan for the TMDL document?

Because monitoring and adaptive management will be key elements of most sediment TMDLs, the TMDL should contain a monitoring and adaptive management plan (USEPA, 1991a, 1999). The plan should incorporate each of the components discussed above along with the rationale for the monitoring and adaptive management approach. The plan should clearly indicate the monitoring goals and hypotheses, the parameters to be monitored, the locations and frequency of monitoring, the monitoring methods to be used, the schedule for review and potential revision, and the parties responsible for implementing the plan. If it is infeasible to develop the monitoring plan in detail at the time of TMDL adoption, it might be adequate to identify only the basic monitoring goals, the review time frame, and the responsible parties while committing to develop the full monitoring plan in the near future.

6. What changes does the proposed rule speak to?

On August 23, 1999, EPA published proposed rules that specify that approvable TMDLs must include at a minimum ten elements. Within the monitoring step, an approvable TMDL will need to include a monitoring plan as part of the implementation plan. The monitoring plan needs to determine the effectiveness of control actions and/or management measures being implemented and whether the TMDL is working, as well as a procedure that will be followed if components of a TMDL must be refined. The plan should clearly indicate the monitoring goals and hypotheses, the parameters to be monitored, the locations and frequency of monitoring, the monitoring methods to be used, the schedule for review and potential revision, and the parties responsible for implementing the plan. It must contain incremental, measurable targets consistent with the specific implementation action and the time frames for implementing those actions. This information is needed to adequately assess whether the specified actions are sufficient to attain water quality standards.

The following are key factors to consider when developing a TMDL monitoring plan:

- *Need to evaluate specific TMDL components.* TMDL problem identification, indicators, numeric targets, source estimates, and allocations might need reevaluation to determine whether they are accurate and effective. The monitoring plan should define specific questions to be answered about these components through the collection of monitoring information.

- *Need to evaluate implementation actions.* It is often important to determine whether actions identified in the implementation plan were actually carried out (implementation monitoring) and whether these actions were effective in attaining TMDL allocations (effectiveness monitoring). Specific questions to be answered concerning implementation actions should be articulated as part of the monitoring plan.

- *Stakeholder goals for monitoring efforts.* Watershed stakeholders often participate in follow-up monitoring, and their interests, in addition to TMDL analysis, should be considered in devising monitoring plans.

- *Existing monitoring activities, resources, and capabilities.* Analysts should identify existing and planned monitoring activities to address TMDL monitoring needs in concert with these efforts, particularly where a long-term monitoring program is envisioned, the study area is large, or water quality agency monitoring resources are limited. Staff capabilities and training should also be considered to ensure that monitoring plans are feasible.

- *Practical constraints to monitoring.* Monitoring options can be limited by practical constraints (e.g., problems with access to monitoring sites and concerns about indirect impacts of monitoring on habitat).

RECOMMENDATIONS FOR FOLLOW-UP MONITORING AND EVALUATION

- Clearly identify the goals of the monitoring program.
- Define specific questions to be answered concerning the evaluation of individual TMDL elements.
- If possible, coordinate with other existing or planned monitoring activities.
- Determine which type or types of monitoring (e.g., implementation, trend) are appropriate for accomplishing the desired goals.
- Develop an appropriate quality assurance plan; follow-up monitoring should be designed to yield defensible data that can support future analysis.

RECOMMENDED READING

(Note that the full list of references for this chapter is included at the end of the document).

MacDonald, L., A.W. Smart, and R.C. Wissmar. 1991. *Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska.* EPA 910/9-91-001. U.S. Environmental Protection Agency, Region 10, Nonpoint Source Section, Seattle, WA.

USEPA. 1992. *Monitoring guidance for the national estuary program.* EPA 842 B-92-004. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1996. *Nonpoint source monitoring and evaluation guide.* Draft final, November 1996. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Assembling the TMDL

Objective: Clearly identify components of a TMDL submittal to support adequate public participation and to facilitate TMDL review and approval.

Procedure: Compile all pertinent information used to develop the TMDL and prepare the final submittal. The final submittal should be supported by documentation for all major assumptions and analyses.

OVERVIEW

It is important to clearly identify the "pieces" of the TMDL submittal and to show how they fit together to provide a coherent planning tool that can lead to attainment of water quality standards for sediment-related water quality impairments. Where TMDLs are derived from other analyses or reports, it is helpful to develop a separate document or chapter that ties together the TMDL components and shows where background information can be found.

RECOMMENDATIONS REGARDING CONTENT OF SUBMITTALS

Section 303(d) of the CWA and EPA's implementing regulations specify that a TMDL consists of the sum of wasteload allocations for future and existing point sources and load allocations for future and existing nonpoint sources and natural background, considering seasonal variation and a margin of safety. These loads are established at levels necessary to implement applicable water quality standards with seasonal and interannual variation and a margin of safety. Experience indicates, however, that information in addition to the statutory and regulatory requirements is useful to ensure adequate public participation and to facilitate EPA review and approval. Since the state and EPA are partners in the TMDL development process, it is in their best interest to work together to determine how much supporting information is needed in the TMDL submittal.

Recommended Minimum Submittal Information

The following list of elements provides a suggested outline for TMDL submittals:

1. Submittal Letter
   - Each TMDL submitted to EPA should be accompanied by a submittal letter stating that the submittal is a draft or final TMDL submitted under section 303(d) of the CWA for EPA review and approval.

2. Problem Statement
   - Waterbody name and location.
   - A map is especially useful if information displayed indicates the area covered by the TMDL (e.g., watershed boundary or upper and lower bounds on the receiving stream segment) and the location of sources.
   - Waterbody section 303(d) list status (including pollutant of concern for the TMDL).
   - Watershed description (e.g., the land cover/land use, geology/hydrology).

3. Applicable Water Quality Standards and Water Quality Numeric Targets
   - Description of applicable water quality standards including designated use(s) affected by the pollutant of concern, numeric or narrative criteria, and the antidegradation policy.
   - If the TMDL is based on a target other than a numeric water quality criteria, provide a description of the process used to derive the target.

4. Pollutant Assessment
   - Source inventory with location of
     - Background
     - Point sources
     - Nonpoint sources
   - Supporting documentation for the analysis of pollutant loads from each of the sources.

5. Linkage Analysis
   - Rationale for the analytical method used to establish the cause-and-effect relationship between the numeric target and the identified pollutant sources.
   - Supporting documentation for the analysis (e.g., basis for assumptions, strengths and weaknesses in the analytical process, results from water quality modeling).

6. TMDL and Allocations
   - Total Maximum Daily Load (TMDL)[1]
     - The TMDL is expressed as the sum of the WLAs, the LAs, and the MOS (if an explicit MOS is included).
     - If the TMDL is expressed in terms other than mass per time, an explanation should be provided for the selection of the other appropriate measure.
   - Wasteload Allocations (WLAs)[2]
     - Loads allocated to existing and future point sources.
     - An explanation of any WLAs based on the assumption that loads from a nonpoint source will be reduced.
     - If no point sources are present, the WLA should be explicitly expressed as zero.
   - Load Allocations (LAs)[2]
     - Loads allocated to existing and future nonpoint sources.
     - Loads allocated to natural background, where it is possible to separate them from nonpoint sources.
     - If there are no nonpoint sources or natural background, the LA should be explicitly expressed as zero.
   - Seasonal Variation[1]
     - Description of the method chosen to account for seasonal and interannual variation.
   - Margin of Safety[1]
     - An implicit MOS is accounted for through conservative assumptions in the analysis. To justify this type of MOS, an explanation of the conservative assumptions used is needed.
     - An explicit MOS is incorporated by setting aside a portion of the TMDL as the MOS.
   - Critical Conditions[2]
     - Critical conditions associated with flow, loading, beneficial use impacts, and other water quality factors are considered.

7. Follow-Up Monitoring Plan
   - Recommended component for TMDLs.
     - Describes the additional data to be collected to determine if load reductions in the TMDL lead to attainment of water quality standards.

8. Public Participation[2]
   - Description of public participation process used.
   - Summary of significant comments received and the responses to those comments.

9. Implementation Plan
   - Implementation plans help establish the basis for approval of TMDLs. They include reasonable assurances that the load allocations in the TMDL for nonpoint sources will be achieved.

Supplementary TMDL Submittal Information

In addition to the information described above, TMDL submittals can be improved by preparing supplemental information, including a TMDL summary memorandum, a TMDL executive summary, a TMDL technical report, and an administrative record. The effort required to develop these documents should be minimal because they are largely a repackaging of information contained in the TMDL submittal. For example, the TMDL executive summary would be prepared for inclusion in the TMDL technical report but would also be ideal for press releases or distribution to the public.

The *TMDL summary memorandum* provides an overview of all the essential regulatory elements of a TMDL submittal. This overview can facilitate regulatory and legal review. The summary memo should include the following information:

- Waterbody (name, size) and location
- Pollutant of concern

[1]Required by statute.

[2]Required by regulation.

- Primary pollutant source(s)
- Applicable water quality standards
- Major data/information sources
- Linkage analysis and load capacity
- WLA, LA, MOS, critical condition, background concentrations, consideration of seasonal variation
- Implementation
- Reasonable assurance
- Follow-up monitoring
- Public participation

The *TMDL executive summary* provides an overview of the TMDL, the conclusions and implications, the analyses, and the background. This document is useful for public information, news releases, and public hearing announcements.

The *TMDL technical report* provides a compilation of the information sources, technical analyses, assumptions, and conclusions. This document provides a summary of the technical basis and rationale used in deriving the TMDL. A sample report outline might include the following sections:

1. Executive Summary
2. Introduction
3. TMDL Indicators and Numeric Targets
4. Water Quality Assessment
5. Source Assessment
6. Linking the Sources to the Indicators/Targets
7. Allocation
8. Implementation
9. Monitoring
10. References

The *administrative record* provides the technical backup, sources of information, calculations, and analyses used in deriving the TMDL. After-the-fact explanations or justifications of EPA's decisions are generally not permitted. A typical administrative record might include the following:

- Spreadsheets
- Modeling software, input/output files
  - Description of the methodology/models used, and a description of the data used for the models.
- References
  - List or index of all documents relied upon by the state or EPA in making decision.
- Reports
  - Including any EPA documents i.e., national/ regional guidance, interpretations, protocols, technical documents relied upon in making decision.
  - Comments/correspondence from outside parties and EPA's or state's responses, including copies of public notice seeking comment, and final decision document.
- Communication
  - Documentation of communication between EPA and the state or EPA and other federal agencies regarding the TMDL.
- Paper calculations
- Maps (working copies)

Public Participation

Public participation is a requirement of the TMDL process and is vital to a TMDL's success. The August 23, 1999, proposed regulation states that the public must be allowed at least 30 days to review and comment on a TMDL prior to its submission to EPA for review and approval. In addition, with its TMDL submittal, a State, Territory, or authorized Tribe must provide EPA with a summary of all public comments received regarding the TMDL and the State's, Territory's, or authorized Tribe's response to those comments, indicating how the comments were considered in the final decision.

EPA believes, however, that stakeholders can contribute much more than their comments on a specific TMDL during the public review process. Given the opportunity, stakeholders can contribute credible, useful data and information about an impaired or threatened water body. They may also be able to raise funds for monitoring or to implement a specific control action and/or management measure.

More importantly, stakeholders can offer insights about their community that may ensure the success of one TMDL allocation strategy over an alternative, as well as the success of follow-up monitoring and evaluation activities. Stakeholders possess knowledge about a community's priorities, how decisions are made locally, and how different residents of a watershed interact with one another. A thorough understanding of the social, political, and economic issues of a watershed is as critical to successful TMDL development as an understanding of the technical issues. States, Territories, and authorized Tribes can create a sense of ownership among watershed residents and "discover@ innovative TMDL strategies through a properly managed public participation process.

Each State, Territory and authorized Tribe is required to establish and maintain a continuing planning process (CPP) as described in section 303(e) of the Clean Water Act. A CPP contains, among other items, a description of the process that the State, Territory or authorized Tribe uses to identify waters needing water quality based controls, a priority ranking of these waters, the process for developing TMDLs, and a description of the process used to receive public review of each TMDL. EPA encourages States, Territories, and authorized Tribes to use their CPP as the basis for establishing a process for public participation, involvement, and in many cases leadership, in TMDL establishment. On a watershed level, the continuing planning process allows programs to combine or leverage resources for public outreach and involvement, monitoring and assessment, development of management strategies, and implementation.

RECOMMENDED READING

(Note that the full list of references for this chapter is included at the end of the document.)

USEPA. 1991a. *Guidance for water quality-based decisions: The TMDL process.* EPA 440/4-91-001. U.S. Environmental Protection Agency, Assessment and Watershed Protection Division, Washington, DC. <http://www.epa.gov/owow/tmdl/policy.html>

USEPA 1999. *Draft guidance for water quality-based decisions: The TMDL process (Second Edition).* EPA 841-D-99-001. U.S. Environmental Protection Agency, Washington, DC. <http://www.epa.gov/owow/tmdl/proprule.html>

APPENDIX: Case Studies

Deep Creek, Montana, TMDL
Redwood Creek, California, TMDL

TMDL Summary: Deep Creek, Montana[1]

Waterbody Type:	Stream
Pollutant:	Temperature, Sediment
Designated Uses:	Recreation, Aquatic Life, Agriculture
Size of Waterbody:	Main stem length: 24 miles
Size of Watershed:	87.7 square miles
Water Quality Standards:	Narrative
Indicators:	Sediment load, erosive banks, channel length, substrate fines, spawning trout, water temperature, minimum flow
Analytical Approach:	Slope of discharge vs. TSS regression

TMDL Submittal Elements

Loading Capacity:	Set as a measurable goal of several TMDL targets, including suspended sediment load, amount of erosive banks, substrate fines and fish counts.
Load Allocation:	50 percent reduction in percent of reach consisting of erosive banks, reestablishment of lost channel length, reduction in fine sediments, increase the number of female rainbow trout captured at weir, decrease the number of days where maximum temperatures exceed 73 degrees F, target low flows in each reach.
Wasteload Allocation:	Zero; no point sources
Seasonal Variation:	Inherent in analysis
Margin of Safety:	Implicit

Introduction

Deep Creek, a major tributary of the Missouri River located in Townsend, Montana, provides spawning and rearing habitat for rainbow trout and brown trout. Deep Creek is classified by the state of Montana as "B-1," which is "suitable for drinking, culinary and food processing purposes, after conventional treatment; bathing, swimming and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply."

EPA Region 8 approved a sediment TMDL for Deep Creek in 1996. This TMDL illustrates a number of important points. First, it demonstrates how the phased TMDL process can be used to initiate mitigation activities even when there is incomplete knowledge of sediment sources and loading rates. Second, it provides an example of an approved TMDL in which quantitative estimates of assimilative capacity and specific numeric load allocations to individual sediment sources are satisfied through the specification of performance targets, such as percent reduction of length of erosive streambanks, which relate implicitly to load reductions. The TMDL is therefore a dynamic plan of action, not just a static allocation of loads. Finally, this sediment TMDL might be more properly thought of as a plan for addressing degraded stream geomorphology, of which sediment is only one aspect. By focusing on geomorphological aspects, the TMDL is able to simultaneously address a variety of interrelated stressors, including excess sediment loading, elevated temperatures, and degradation of physical habitat.

Problem Identification

A cover memo should describe the waterbody as it is identified on the state's section 303(d) list, the pollutant of concern, and the priority ranking of the waterbody. The TMDL submittal must include a description of the point, nonpoint, and natural background sources of the pollutant of concern, including the magnitude and

[1] All information contained in this summary was obtained from Endicott and McMahon, 1996.

location of the sources. The TMDL submittal should also contain a description of any important assumptions, such as (1) the assumed distribution of land use in the watershed; (2) population characteristics, wildlife resources, and other relevant characteristics affecting pollutant characterization and allocation, as applicable; (3) present and future growth trends, if this factor was taken into consideration in preparing the TMDL; and (4) an explanation and analytical basis for expressing the TMDL through surrogate measures, if applicable.

Deep Creek supports the valuable Missouri River/Canyon Ferry Reservoir cold-water trout fishery. The Canyon Ferry Reservoir is one of the most heavily fished bodies of water in Montana, and the condition of the fishery has long been a concern of the Montana Department of Fish, Wildlife & Parks (MDFWP). Detailed studies were undertaken in connection with mitigation of impacts associated with the construction of Toston Dam on the Missouri River. Construction of the dam had isolated a stretch of the Missouri River between the dam and Canyon Ferry Reservoir, leaving Deep Creek as one of the few spawning streams in the isolated reach. A major physical barrier to spawning trout was remedied in 1991 by routing Montana Ditch under Deep Creek with a siphon. Despite the Montana Ditch routing effort, however, concerns over habitat quality remained.

The Natural Resources Conservation Service (NRCS) developed an inventory of watershed land use using aerial photographs and analyzed the condition and stability of the channel by applying a Rosgen geomorphological analysis. Intensive monitoring of flows, temperature, suspended sediment, and chemical water quality was conducted between 1988 and 1994 at a variety of locations within Deep Creek. Biological data include trout counts at the Montana Ditch siphon and redd counts taken by the MDFWP. Rapid Bioassessment Protocol (RBP) analyses of benthic macroinvertebrate communities have also been performed in several reaches of Deep Creek. These data provide the basis for development of the TMDL and are summarized in Endicott and McMahon (1996).

Designated uses of Deep Creek include recreation, support for aquatic life, and agricultural water supply, but the major concern leading to the TMDL was support for the trout fishery. Analysis of the available chemical, physical, and biological data led to the formation of a set of interlinked hypotheses explaining the poor support of designated uses, summarized by Endicott and McMahon (1996) as follows:

> . . . aquatic life in Deep Creek is impaired by several types of habitat degradation. Degraded instream habitat and water quality in Deep Creek is the result of degradation of riparian vegetation communities and dewatering. Bank stability is poor throughout the lower reaches resulting in bank collapse, loss of meander bends, stream entrenchment and high suspended and deposited fine sediment. Water temperatures become elevated due to limited riparian shading and dewatering. Dewatering may also impair migration of juvenile salmonids to the Missouri River. The combined effects of degradation on Deep Creek results in impacts on aquatic life which can be seen in the low production of juvenile trout and alteration in communities of benthic macroinvertebrates [in downstream reaches]. . . .

These various types and sources of degradation are linked because all reflect modifications to the natural form of the stream channel and the stream's riparian area. Thus, the set of linked causes of nonsupport are addressed through a TMDL for sediment and stream geomorphology. It is noted that in addition to the TMDL for sediment, TMDLs (and target values) for lack of flow and for temperature[2] have also been established for Deep Creek. Although each TMDL is designed to address separate concerns, all three are interrelated since the impacts of both reduced flow and temperature are closely linked to the impacts addressed in the sediment TMDL.

Description of the Applicable Water Quality Standards and Numeric Water Quality Target

The TMDL submittal must include a description of the applicable state water quality standard, including the designated use(s) of the waterbody, the applicable numeric or narrative water quality criterion, and the

[2] Montana has no absolute temperature standards, but has established standards that prevent certain excursions from natural ambient temperature values.

antidegradation policy. This information is necessary for EPA to review the load and wasteload allocations required by the regulation. A numeric water quality target for the TMDL (a quantitative value used to measure whether the applicable water quality standard is attained) must be identified. If the TMDL is based on a target other than a numeric water quality criterion, a description of the process used to derive the target must be included in the submittal.

As is the case with many sediment TMDLs, management of Deep Creek is framed in terms of attainment of narrative standards and designated uses, and no numeric water quality standards are relevant to the problem. How then were target values of water quality indicators established? The Deep Creek TMDL developers (Endicott and McMahon, 1996) state "while the title 'TMDL' implies that . . . goals are expressed in terms of concentrations or levels of a given pollutant, a TMDL can be phrased in terms of any quantifiable goal related to the aquatic system. For example, a TMDL can be defined as established decreases in eroding bank or measured increases in trout recruitment." This broad interpretation is justified in light of EPA's guidance for phased TMDLs. EPA (1991) suggests use of a phased approach for TMDLs for water quality-limited waterbodies where loading estimates are based on limited information. Further, EPA regulations (40 CFR 130.2(g)) define load allocations for nonpoint sources as "best estimates of the loading which may range from reasonably accurate estimates to gross allotments . . . ." The phased approach requires adaptive management where initial load allocations or mitigation strategies are established based on best estimates and are subsequently refined as responses to these actions are observed.

For Deep Creek, water quality indicators were identified and associated target values were developed based on problem identification using the available information and professional judgment and with the expectation that the targets would be revised through additional monitoring and adaptive management. The use of more than one indicator was desirable for Deep Creek to account for system complexity, multiple stressors, and the lack of certainty regarding the effectiveness of each indicator and its numeric target values. Additionally, the use of multiple indicators allows tracking of both source control and attainment of uses, even though there is uncertainty in the exact linkage between sources and uses.

Five broad categories are applicable to sediment TMDL indicators: (1) water column indicators, (2) streambed sediment indicators, (3) biological indicators, (4) channel condition indicators such as channel form and stability, and (5) riparian and hillslope indicators. For Deep Creek, four different indicators and associated target values were proposed. The indicators and targets are listed below with the applicable TMDL indicator category in parentheses.

1. *Suspended sediment load* (a water column sediment indicator). Obtain a measurable reduction in suspended sediment load by decreasing the slope and intercept of the regression line between discharge and total suspended solids (TSS) by half in 4 out of 5 years or by demonstrating no significant difference in daily TSS load between Deep Creek and an unimpaired reference stream during spring runoff in 4 out of 5 years. The utility of using the reference reach daily TSS load approach may not be as great as that of the discharge vs. TSS relationship approach because the daily TSS load approach is more limited in terms of acknowledging the variability of the system. Because Deep Creek is a dynamic system that experiences significant loading during wet weather events, the discharge vs. TSS relationship may be more relevant.

2. *Substrate fines* (streambed sediment indicator). Reduce substrate fines (<6.35 mm) in spawning riffles from 50 percent to 30 percent over the next 5 years.

3. *Spawning trout* (biological indicator). Meet a target of 3,000 spawning female wild trout per year entering Deep Creek from the Missouri River over the next 10 years.

4. *Water temperature.* Reduce water temperature extremes so that temperatures do not exceed 73 °F for more than 10 days per year along the length of Deep Creek.

In addition to the four indicator targets noted above, three other quantifiable goals associated with achievement of the specified in-stream targets were identified and set as the TMDL for Deep Creek. For this type of TMDL, it is important to understand that the indicator target values are reasonable benchmarks for measuring progress, rather than enforceable goals.

Source Assessment

The geographic scope of the TMDL is the entire Deep Creek watershed. Within this general geographic area, however, the TMDL focuses on specific critical areas identified by a source assessment. The source assessment for Deep Creek is based on a reach-by-reach analysis of channel condition and geomorphology. It includes historical analysis of changes in stream length and sinuosity based on the review of aerial photographs and the estimation of stability for each erosive bank based on streambank inventories of each reach of Deep Creek.

The analysis indicates that unstable banks are a key source of the sediment loading that results in impairment of uses. A detailed, reach-by-reach analysis of channel morphology and bank stability identified critical areas for mitigation and established a basis for prioritizing initial control efforts. Accordingly, the priorities identified for remediation include the prevention of additional loss of channel length and the stabilization of streambanks and riparian areas that are significant sources of sediment in the most highly impacted reaches.

The source assessment reflects the working hypotheses of causes of use impairment in Deep Creek. Degradation of habitat condition in Deep Creek was originally caused by a combination of increased watershed sediment loads, reduction in flow volume, and some artificial channel straightening. These stressors initiated a complex chain of geomorphological events, which led to loss of meanders, shortening of the stream and incision into the floodplain, and erosion of streambanks. Increased bedload requires increased hydraulic energy for transport, resulting in straightening of the stream; increasing gradient, width, and wavelength; and decreasing depth. Increasing gradient, however, results in undermining of banks, generation of additional sediment load, and a cycle of continued degradation, which cannot be addressed through upland watershed controls alone. In the short term, eroding banks represent the major source of stressor loading to Deep Creek and thus are the priority for the first phase of a phased TMDL.

Loading Capacity: Linking Water Quality and Pollutant Sources

As described in EPA guidance, a TMDL describes the loading capacity of a waterbody for a particular pollutant. EPA regulations define loading capacity as the greatest amount of loading that a waterbody can receive without violating water quality standards (40 CFR 130.2(f)). The TMDL submittal must describe the rationale for the analytical method used to establish the cause-and-effect relationship between the numeric target and the identified pollutant sources. In many circumstances, a *critical condition* must be described and related to physical conditions in the waterbody (40 CFR 130.7(c)(1)). Supporting documentation for the analysis must also be included, including the basis for assumptions, strengths and weaknesses in the analytical process, and results from water quality modeling, so that EPA can properly review the elements of the TMDL that are required by the statute and regulations.

The linkage analysis should establish the cause-and-effect relationships between measurable water quality targets and identified sources. There are various ways of drawing this linkage, including the use of a cause/effect model to predict the result of applying source control with respect to meeting targets, monitoring data to associate waterbody responses to flow and loading conditions, statistical and analytical tools, and best professional judgment. Another option is to use a reference reach approach that takes conditions from a healthy stream and establishes them as targets for the unhealthy stream. Using the reference reach approach, conditions may have to be normalized or otherwise adjusted for the unhealthy stream, but the approach can be helpful in establishing sediment criteria as well as sediment TMDLs and in providing the linkage between source control and targets.

For Deep Creek, this established linkage consists primarily of analysis of observations (including statistical analyses) and best professional judgment, although a reference reach approach was used to establish a linkage between suspended sediment load and sediment sources. A qualitative analysis of probable geomorphic response was determined to be the most feasible and appropriate method for Deep Creek. It is noted that a lack of a quantitative linkage is acceptable in the case of a phased TMDL that emphasizes adaptive management, as is the case for the Deep Creek TMDL.

Allocations

EPA regulations require that a TMDL include wasteload allocation (WLAs), which identify the portion of the loading capacity allocated to existing and future point sources (40 CFR 130.2(g)). If no point sources are present or the TMDL recommends a zero WLA for point sources, the WLA must be listed as zero. The TMDL may recommend a zero WLA if the state determines, after considering all pollutant sources, that allocating only to nonpoint sources will still result in attainment of the applicable water quality standard. In preparing the WLA, it is not necessary that every individual point source have a portion of the allocation of pollutant loading capacity. But it is necessary to allocate the loading capacity among individual point sources as necessary to meet the water quality standard. The TMDL submittal should also discuss whether a WLA is based on an assumption that loads from a nonpoint source or sources will be reduced. In such cases, the state will need to demonstrate reasonable assurance that the nonpoint source reductions will occur within a reasonable time.

EPA regulations require that a TMDL include load allocations (LAs), which identify the portion of the loading capacity allocated to existing and future nonpoint sources and to natural background (40 CFR 130.2(h)). LAs may range from reasonably accurate estimates to gross allotments (40 CFR 130.2(g)). Where it is possible to separate natural background from nonpoint sources, separate LAs should be made and described. If there are neither nonpoint sources nor natural background or the TMDL recommends a zero LA, an explanation must be provided. The TMDL may recommend a zero LA if the state determines, after considering all pollutant sources, that allocating only to point sources will still result in attainment of the applicable water quality standard.

The statute and regulations require that a TMDL include a margin of safety to account for any lack of knowledge concerning the relationship between effluent limitations and water quality (CWA § 303(d)(1)(C), 40 CFR 130.7(c)(1)). EPA guidance explains that the MOS may be implicit, i.e., incorporated into the TMDL through conservative assumptions in the analysis, or explicit, i.e., expressed in the TMDL as loadings set aside for the MOS. If the MOS is implicit, the conservative assumptions in the analysis that account for the MOS must be described. If the MOS is explicit, the loading set aside for the MOS must be identified.

The statute and regulations require that a TMDL be established with seasonal variations. The method chosen for including seasonal variations in the TMDL must be described (CWA § 303(d)(1)(C), 40 CFR 130.7(c)(1)).

For many TMDL, allocations consist of assigning specific, quantitative load allocations and wasteload allocations, expressed in terms of mass per time loading rates, to each source of a stressor. In some cases this will involve development of allocations for each individual facility and landowner. Allocations, however, are not necessarily equivalent to identifying "who is to blame." Instead, the basic objective is to develop recommendations for load reductions that are distributed among the various sources while demonstrating that implementation of the allocations will achieve numeric targets.

In the case of Deep Creek, the primary immediate threats are due to unstable banks and loss of meanders, regardless of what processes initiated geomorphic disturbance in the stream. The allocation consists in large part of determining which streambanks have the greatest potential to contribute sediment loads and then planning stabilization for these high-priority banks. Therefore, the allocation is expressed in terms of relative threat rather than a known loading rate. Bank stabilization activities for Deep Creek will consist of installing juniper revetments, planting vegetation, and excluding cattle from riparian areas. One management practice implemented in 1992 that has eliminated a major sediment source was the improvement of the annual start-up and shut-down practices of the Broadwater-Missouri ditch (Endicott and McMahon, 1996). This best management practice (BMP) has significantly decreased sediment pulses from the ditch to

Deep Creek and provides a good example to consider for similar systems.

The TMDLs established for Deep Creek are intended to indicate the level of pollutant reduction needed to achieve the in-stream targets (e.g., regarding substrate fines, spawning trout) and are related to a decrease in the intensity of sediment loading. The TMDLs developed for Deep Creek are as follows:

1. *Percentage of eroding bank.* Decrease the percentage of eroding streambanks by 50 percent over the next 10 years, with target conditions established by reach.

2. *Channel length.* Over the next 5 years, reestablish 2,275 feet of channel length in meanders (25 percent of the length of channel that has been lost to meander reduction and degradation since 1955).

3. *Minimum flow.* Maintain minimum flows of not less than 9 cubic feet per second (cfs) in the lower and upper reaches of Deep Creek and not less than 3 cfs in the middle reaches.

Although the discrepancy between the four indicator target values and the three TMDL values may be considered slight, the differentiation helps to clarify which indicators are more indicative of suitable fish habitat and a healthy trout population (i.e., four target values) and which are more indicative of source control (i.e., three TMDL values). The indicator target values are linked to the designated uses of the waterbody and relevant narrative provisions in the state water quality standards and, therefore, can be used to measure success toward meeting those standards and attaining designated uses. The TMDL values represent the sediment load reductions needed to meet target values and achieve water quality standards.

Within the phased TMDL process, the ability to achieve numeric targets is uncertain, although the proposed remediation efforts represent a good faith attempt to achieve these targets. It is fully expected that management strategies and the specific allocations implied by these management strategies are likely to change as monitoring continues.

Monitoring Plan for TMDLs Developed Under the Phased Approach

EPA's 1991 document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA 440/4-91-001), calls for a monitoring plan when a TMDL is developed under the phased approach. The guidance provides that a TMDL developed under the phased approach also needs to provide assurances that nonpoint source control measures will achieve expected load reductions. The phased approach is appropriate when a TMDL involves both point and nonpoint sources and the point source WLA is based on an LA for which nonpoint source controls need to be implemented. Therefore, EPA's guidance provides that a TMDL developed under the phased approach should include a monitoring plan that describes the additional data to be collected to determine if the load reductions required by the TMDL lead to attainment of water quality standards.

A plan for continued monitoring is a key and required component of any phased TMDL. The Deep Creek TMDL recognizes the importance of monitoring to guide the adaptive management process and includes detailed proposals for monitoring in accordance with the general goals specified by Endicott and McMahon (1996):

> . . . the proposed monitoring tools cover aspects of water quality, channel morphology, substrate characteristics, and aquatic biota. Monitoring protocols should be applied yearly for between 5 and 10 years . . . following treatment. While not all the proposed monitoring procedures . . . need to be implemented, it is important to design a monitoring protocol for each of the TMDL targets. In addition, because landowner involvement is so important to the success of this [TMDL], monitoring tools that can be implemented by landowners should be considered.

Endicott and McMahon (1996) recommend the following monitoring components and techniques for analyzing and tracking progress in Deep Creek:

- Annual completion by landowners along Deep Creek of the riparian monitoring questionnaire developed by the Montana Riparian Association.

The questionnaire is designed to assess the effects of land management on riparian stream conditions and troubleshoot problems like excessive soil erosion.

- Monitoring total suspended sediment and discharge through spring runoff. This monitoring will support the relationship between discharge and TSS and the calculation of the yearly load of suspended sediment.

- Continued monitoring of water temperature to assess progress toward temperature targets, including the installation of recording thermographs in the 11 reaches of Deep Creek.

- Measurement of substrate sedimentation by methods, including substrate core sample analysis, Wolman pebble counts, and photo series of substrate at specified locations.

- Measurement of channel morphology changes at permanent transect locations.

- Establishment of a photographic record of fluvial and habitat changes at permanent photo points.

- Continued counts of fish at the permanent weirs at the Montana Ditch siphon coupled with monitoring of artificial redds and the completion of a basin fish and fish habitat survey.

- Continued application of the RBPs to assess changes in habitat conditions and benthic macroinvertebrate communities.

Implementation Plans/Reasonable Assurances

On August 8, 1997, Bob Perciasepe issued a memorandum, "New Policies for Establishing and Implementing Total Maximum Daily Loads (TMDLs)," which directs EPA regions to work in partnership with states to achieve nonpoint source load allocations established for 303(d)-listed waters impaired solely or primarily by nonpoint sources. To this end, the memorandum asks that regions assist states in developing implementation plans that include reasonable assurances that the nonpoint source load allocations established in TMDLs for waters impaired solely or primarily by nonpoint sources will in fact be achieved; a public participation process; and recognition of other relevant watershed management processes. In a water impaired by both point and nonpoint sources, where a point source is given a less stringent wasteload allocation based on an assumption that nonpoint source load reductions will occur, reasonable assurance must be provided for the TMDL to be approvable. This information is necessary for EPA to review the load and wasteload allocations required by the regulation. Although implementation plans are not approved by EPA, they help establish the basis for EPA's approval of TMDLs.

In a water impaired solely by nonpoint sources, reasonable assurances are not required for a TMDL to be approvable. For such nonpoint source-only waters, states are encouraged to provide reasonable assurances regarding achievement of load allocations in the implementation plans described in section 7, above. As described in the August 8, 1997, memorandum, such reasonable assurances should be included in state implementation plans and "may be non-regulatory, regulatory, or incentive-based, consistent with applicable laws and programs." Endicott and McMahon (1996) recommend a variety of stream restoration activities along Deep Creek that would increase bank stability, decrease erosion, and increase the health of the fishery by reducing sediment stresses and improving fish habitat to meet water quality targets. Based on existing data, a number of reach specific recommendations for remediation on Deep Creek are proposed. Restoration implementation activities include the channel modifications, installation of juniper revetments, riparian BMPs, willow plantings, widening of riparian zone width, increases in channel length, and fencing to exclude livestock from the stream and riparian areas.

References

Endicott, C.L., and T.E. McMahon. 1996. *Development of a TMDL to reduce nonpoint source sediment pollution in Deep Creek, Montana*. Report to Montana Department of Environmental Quality.

Contact: Bruce Zander, Region 8 TMDL Coordinator • United States Environmental Protection Agency Region 8 • 999 18th Street Suite 500 • Denver, CO 80202 • (303) 312-6846 • zander.bruce@epa.gov

TMDL Summary: Redwood Creek, California

Waterbody Type:	Stream
Pollutant:	Sediment
Designated Uses:	Cold freshwater habitat; migration of aquatic organisms; estuarine habitat; community, military, or individual system use, including drinking water; maintenance of rare, threatened, or endangered plant or animal species; spawning, reproduction, and/or early development
Size of Waterbody:	63 miles long
Size of Watershed:	285 square miles
Water Quality Standards:	Narrative
Indicators:	In-stream - percent fines, percent riffles, pool depth, median particle size diameter, large woody debris Hillslope - stream crossings, road culvert sizing, land/road fill stability, road surfacing/ drainage, road inspection, maintenance, decommissioning, road location, and timber harvest methods.
Analytical Approach:	Partial sediment budget; reference reach comparison

Introduction

Redwood Creek watershed is a 285-mi^2 forested watershed in Humboldt County in northwestern California. Redwood Creek flows into the Pacific Ocean near Orick, California. The watershed is narrow and elongated (65 miles in length and 4 to 7 miles wide) with mostly mountainous and forested terrain.

Elevations within the watershed range from sea level to 5,300 feet. Redwood National Park composes the lower portion of the watershed, and timber and livestock production are the primary land uses upstream of the park. Redwood Creek is designated for use as a cold water fishery. The creek has historically supported large numbers of coho salmon, chinook salmon, steelhead trout, and other fish species.

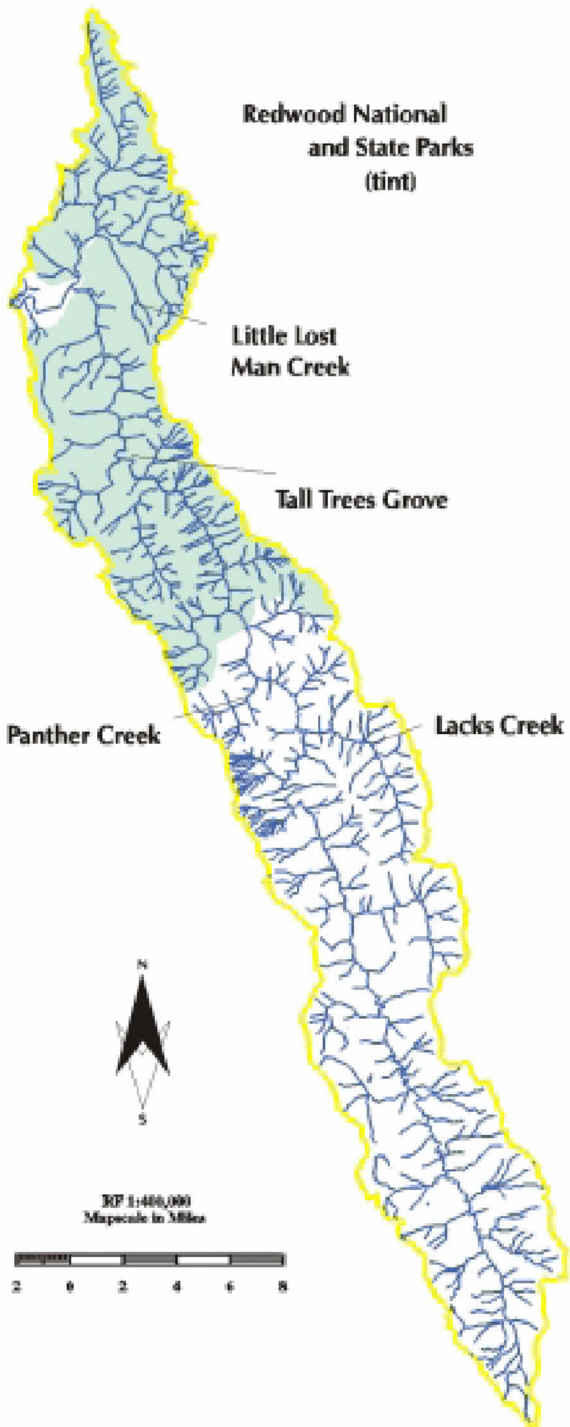
USEPA Region 9 approved the sediment TMDL for Redwood Creek in December 1998. This summary is based on information contained in *Redwood Creek Sediment Total Maximum Daily Load* (USEPA, 1998).

TMDL Submittal Elements

Loading Capacity:	1,900 tons/square mile/year
Load Allocation:	1,900 tons/square mile/year
Wasteload Allocation:	Zero - No point sources
Seasonal Variation:	Inherent annual and seasonal variation in the delivery of sediment to streams
Margin of Safety:	Implicit through conservative assumptions

Problem Identification

A cover memo should describe the waterbody as it is identified on the state's section 303(d) list, the pollutant of concern, and the priority ranking of the waterbody. The TMDL submittal must include a description of the point, nonpoint, and natural background sources of the pollutant of concern, including the magnitude and location of the sources. The TMDL submittal should also contain a description of any important assumptions, such as (1) the assumed distribution of land use in the watershed; (2) population characteristics, wildlife resources, and other relevant characteristics affecting pollutant characterization and allocation, as applicable; (3) present and future growth trends, if this factor was taken into consideration in preparing the TMDL; and (4) an explanation and analytical basis for expressing the TMDL through surrogate measures, if applicable.



Redwood Creek watershed was listed on California's 1992 section 303(d) list as impaired due to sedimentation, the levels of which violated the existing water quality objective for protecting designated uses, particularly the cold water fishery. Accelerated erosion and other causes of sedimentation are adversely affecting the migration, spawning, reproduction, and early development of coho salmon, chinook salmon, and steelhead trout.

Because the native fishery of Redwood Creek is largely free of the effects of non-native aquatic species or hatchery stocks, the creek's ability to support fish populations is determined primarily by habitat quality and availability. The Redwood Creek TMDL for sediment addresses habitat quality impacts associated with excessive sediment, specifically pool quality, gravel quality (for spawning and food production), and changes in channel structure contributing to increased temperature. Although Redwood Creek is prone to storm-induced erosional events and the watershed has natural geologic instability, land management activities have accelerated the natural erosion process, overwhelming the stream channel's ability to efficiently remove the excess sediment.

Specific in-stream problems in Redwood Creek include fine sediment in spawning gravels, channel aggradation, lack of suitable pools for rearing habitats, stream channel instability, and physical barriers to migration. Specific hillslope problems in the watershed include improperly designed or maintained roads, sediment from unstable areas, removal of riparian trees, and loss of large woody debris.

Description of the Applicable Water Quality Standards and Numeric Water Quality Target

The TMDL submittal must include a description of the applicable state water quality standards, including the designated use(s) of the waterbody, the applicable numeric or narrative water quality criterion, and the antidegradation policy. This information is necessary for EPA to review the load and wasteload allocations required by the regulation. A numeric water quality target for the TMDL (a quantitative value used to measure whether the applicable water quality standard is attained) must be identified. If the TMDL is based on a target other than a numeric water quality criterion, a description of the process used to derive the target must be included in the submittal.

The state of California has established water quality objectives (WQOs) to protect designated uses. The

WQO that addresses settleable material and sediment is as follows:

- Water shall not contain substances that result in deposition of material that causes nuisance or adversely affect beneficial uses.

- The suspended sediment load and suspended sediment discharge rate of surface water shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.

Because the applicable water quality standards are narrative, it was necessary to identify some measurable parameters (indicators) to evaluate the relationship between pollutant sources and their impact on water quality. The analysts then quantified numeric target values for the indicators that represent conditions that meet water quality standards and support designated uses. Various types of indicators are available for sediment, including water column, streambed/channel, biological, and hillslope indicators.

The numeric targets developed for the Redwood Creek sediment TMDL inlcuded both streambed targets and hillslope targets (Tables 1 and 2). The in-stream streambed numeric targets represent adequate aquatic habitat conditions for salmonid reproductive success. Hillslope targets provide additional indicators of environmental conditions associated with designated use protection. The hillslope indicators complement in-stream indicators and reflect the watershed erosional conditions. They represent land management conditions associated with erosional processes and erosion rates that are not excessively accelerated by human activities. The numeric targets were based on scientific literature, available monitoring data for the basin, and best professional judgment. The numeric targets interpret the narrative water quality standards to:

- Describe the physical conditions of Redwood Creek and the surrounding hillslopes that relate to the designated use.
- Assist in estimating the creek's capacity to receive future sediment inputs and still support designated uses.
- Compare existing and target conditions for sediment-related indicators.
- Provide a framework for future data analysis and review of the TMDL or implementation plan.
- Assist in evaluating the effectiveness of land management and restoration actions in adequately reducing erosion and subsequent sediment loading to the creek.

Source Assessment

Ten categories of sediment delivery were identified for the Redwood Creek watershed, eight of which were characterized as controllable, as follows:

Table 1. In-stream numeric targets representing desired conditions for Redwood Creek

Indicator	*Numeric Target*
Percent fines <0.85 mm in riffle crests of fish-bearing streams	<14%
Percent fines <6.5 mm in riffle crests of fish-bearing streams	<30%
Percent of stream length in riffles	<25%-30% of stream reaches in riffles (reach gradient <2%)
Pool depth in main stem Redwood Creek reaches with pool-riffle morphology	mean depth of pools at low flow >2 m
Depths of pools in 3rd and 4th order tributaries with pool-riffle morphology	mean depth of pools at low flow >1-1.5 m
Median particle size diameter (d50) from riffle crest surfaces	≥37 mm (minimum for a reach) ≥69 (mean for a reach)
Percent fines <2 mm at riffle crest surfaces in fish-bearing streams	<10%-20%
Large woody debris in any watercourse capable of transporting sediment to a higher-order watercourse	Improving trend toward increased large woody debris

Table 2. Hillslope numeric targets representing desired conditions for Redwood Creek

Indicator	*Numeric Target*
Road stream crossings with diversion potential	No crossings have diversion potential (i.e., all crossings are reconfigured permanently to ensure that no diversion will occur).
Road culvert/crossing sizing	All culverts and crossings are sized to pass the 50-year flood and associated sediment and debris. In addition, crossings and culverts in the snow zone are sized large enough to accommodate flows and associated sediment and debris caused by precipitation and snowmelt runoff.
Landing and road fill stability	All landings and road fills (e.g., sidecasts) that are on slopes >50% and could potentially deliver sediment to a watercourse are pulled back and stabilized.
Road surfacing and drainage	All roads have surfacing and drainage facilities or structures that are appropriate to their patterns and intensity of use.
Road inspection, maintenance, and decommissioning	All roads are inspected and maintained annually or decommissioned. Decommissioned roads (roads which are closed, abandoned, or obliterated) are hydrologically maintenance-free.
Road location in inner gorge or unstable headwall areas	Roads are not located in steep inner gorge or unstable headwall areas except where alternative road locations are unavailable.
Use of clearcut and/or tractor yarding timber harvest methods	Clearcut or tractor yarding harvest methods are not used in steep inner gorge, unstable, or streamside areas unless a detailed geological assessment is performed that shows there is no potential for increased sediment delivery to watercourses as a result of using these methods.

Controllable:

- Erosion associated with roads, skid trails, and landings
- Gully erosion
- Bare ground erosion associated with human activities
- Streambank erosion associated with human activities
- Tributary landslides (road-related)
- Tributary landslides (harvest-related)
- Main stem landslides
- Debris torrents

Uncontrollable:

- Tributary landslides (naturally occurring)
- Other naturally occurring mass movements (e.g., earth flows, block slides)

In evaluating these sources, analysts determined the following information:

- Estimate of average annual sediment loads per square mile for the entire Redwood Creek watershed.
- Estimates of average annual sediment loads per square mile for three "reference" tributary watersheds within the Redwood Creek basin.
- Estimates of historical sediment loading rates from each erosional process category in the watershed.

Geomorphic research and monitoring programs of the National Park Service and the USGS provide two general types of sediment source information for Redwood Creek: (1) measurements of erosional processes within the watershed and (2) records of sediment transport in Redwood Creek and some tributaries. The measurements of erosional processes were used to estimate the relative contributions of different source categories to overall sediment loading, and as the basis for allocating sediment source reductions and the TMDL. The records of sediment transport were used to estimate overall sediment loading rates for the watershed and localized loading rates for three tributaries. The overall loading rate provided the baseline against which TMDL-related sediment reductions were calculated. The localized tributary loading rate information assisted in estimating the future loading capacity of Redwood Creek and the overall sediment discharge reductions needed to protect designated uses. A more detailed discussion of the source assessment, including estimated sediment loads, is contained in USEPA (1998).

Loading Capacity : Linking Water Quality and Pollutant Sources

As described in EPA guidance, a TMDL describes the loading capacity of a waterbody for a particular pollutant. EPA regulations define loading capacity as the greatest amount of loading that a waterbody can receive without violating water quality standards (40 CFR 130.2(f)). The TMDL submittal must describe the rationale for the analytical method used to establish the cause-and-effect relationship between the numeric target and the identified pollutant sources. In many circumstances, a *critical condition* must be described and related to physical conditions in the waterbody (40 CFR 130.7(c)(1)). Supporting documentation for the analysis must also be included, including the basis for assumptions, strengths and weaknesses in the analytical process, and results from water quality modeling, so that EPA can properly review the elements of the TMDL that are required by the statute and regulations.

To determine the magnitude of in-stream sediment problems and the associated levels of sediment source reductions needed to address sediment problems, it is important to evaluate the cause-and-effect relationship between water quality targets and sediment sources. Assessment of the loading capacity of Redwood Creek and of the necessary reductions in sediment loading from sources to meet water quality standards requires the following two analytic methods:

- Qualitative comparison of existing and historical conditions (related to numeric targets).
- Quantitative comparison of average sediment loading rates per square mile, in highly affected and relatively unimpaired areas of the watershed.

The Redwood Creek sediment TMDL recognizes that inferring linkages between hillslope erosion processes and in-stream impacts based on the methods used might produce uncertain results. Because of the lack of direct linkages or reliable methods for modeling those linkages, these inferential methods are necessary to compare existing and desired conditions and to estimate the level of sediment reduction needed to meet water quality standards.

Because of limited historical data, it was not feasible to quantitatively compare historical and target conditions for in-stream indicators. A qualitative analysis of existing conditions related to water quality targets (e.g., percent fines, pool depth) indicated that in-stream conditions are inadequate to support a healthy habitat and that reductions in sediment loading are necessary to support designated uses.

To quantitatively compare existing and "reference" conditions, three tributary subwatersheds within the Redwood Creek watershed were identified and used as reference watersheds. Each reference subwatershed represented different underlying geologies. The loadings from each of the reference conditions were then extrapolated to those areas of the entire watershed having comparative geologies to estimate a single "reference watershed" loading rate for the whole Redwood Creek watershed. Comparison of the existing watershed sediment loading and the "reference watershed" loading values indicated that a reduction of approximately 60 percent in sediment loading was needed to achieve "reference" conditions. Therefore, the sediment loading capacity for Redwood Creek was determined to be 40 percent of the historical average annual loading rate, or 1,900 tons/mi^2/yr.

Allocations

EPA regulations require that a TMDL include wasteload allocations (WLAs), which identify the portion of the loading capacity allocated to existing and future point sources (40 CFR 130.2(g)). If no point sources are present or the TMDL recommends a zero WLA for point sources, the WLA must be listed as zero. The TMDL may recommend a zero WLA if the state determines, after considering all pollutant sources, that allocating only to nonpoint sources will still result in attainment of the applicable water quality standard. In preparing the WLA, it is not necessary that every individual point source have a portion of the allocation of pollutant loading capacity. But it is necessary to allocate the loading capacity among individual point sources as necessary to meet the water quality standard. The TMDL submittal should also discuss whether a WLA is based on an assumption that loads from a nonpoint source or sources will be reduced. In such cases, the state will need to demonstrate reasonable assurance that the nonpoint source reductions will occur within a reasonable time.

EPA regulations require that a TMDL include load allocations (LAs), which identify the portion of the loading capacity allocated to existing and future nonpoint sources and to natural background (40 CFR 130.2(h)). LAs may range from reasonably accurate estimates to gross allotments (40 CFR 130.2(g)). Where it is possible to separate natural background from nonpoint sources, separate load allocations should be made and described. If there are neither nonpoint sources nor natural background or the TMDL recommends a zero LA, an explanation must be provided. The TMDL may recommend a zero LA if the state determines, after considering all pollutant sources, that allocating only to point sources will still result in attainment of the applicable water quality standard.

The statute and regulations require that a TMDL include a margin of safety to account for any lack of knowledge concerning the relationship between effluent limitations and water quality (CWA § 303(d)(1)(C), 40 CFR 130.7(c)(1)). EPA guidance explains that the MOS may be implicit, i.e., incorporated into the TMDL through conservative assumptions in the analysis, or explicit, i.e., expressed in the TMDL as loadings set aside for the MOS. If the MOS is implicit, the conservative assumptions in the analysis that account for the MOS must be described. If the MOS is explicit, the loading set aside for the MOS must be identified.

The statute and regulations require that a TMDL be established with seasonal variations. The method chosen for including seasonal variations in the TMDL must be described (CWA § 303(d)(1)(C), 40 CFR 130.7(c)(1)).

Allocations for the Redwood Creek sediment TMDL are based on erosion processes, which are mostly associated with land use activities. The load allocations for erosion processes are expressed as long-term annual average loads per square mile for the entire watershed. The TMDL is expressed as a 10-year rolling annual average, allowing for the large interannual variability in sediment loading. The TMDL of 1,900 tons/mi^2/year is equal to the loading capacity determined in the linkage analysis. The individual load allocations were based on EPA's assessment of the controllability of loadings from different source categories. The controllable fraction of total loads from each source category was estimated, and the remaining loads were summed and compared to the TMDL. (Controllable sources of sediment were defined as those which are associated with human activity and will respond to mitigation, altered land management, or restoration.) The analysis indicated that the application of reasonable practices plus reduction by the controllable load would result in a decrease that is adequate to meet the TMDL. There are no known point sources in the Redwood Creek watershed, so the wasteload allocation is zero.

Estimates of controllable percentages of loads were derived from field work in the watershed and in nearby watersheds, documented results of sediment control practices within the watershed, literature references, and professional experience.

The Redwood Creek TMDL uses a series of conservative assumptions to fully account for the margin of safety. These assumptions include selection of in-stream numeric target levels, use of hillslope targets, proportion of bedload in total sediment load, sediment storage in the main stem of Redwood Creek, comparison of sediment loading from reference streams with that from Redwood Creek as a whole, association of hillslope sources with human causes, and estimation of loading capacity.

Seasonal variation is inherent in the delivery of sediment to stream systems. For this reason, the allocations in the Redwood Creek TMDL are designed to apply to the *sources* of sediment, not to the movement of sediment across the landscape or the delivery of sediment directly to the stream channel.

Monitoring Plan for TMDLs Developed Under the Phased Approach

EPA's 1991 document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA 440/4-91-001), calls for a monitoring plan when a TMDL is developed under the phased approach. The guidance provides that a TMDL developed under the phased approach also needs to provide assurances that nonpoint source control measures will achieve expected load reductions. The phased approach is appropriate when a TMDL involves both point and nonpoint sources and the point source WLA is based on an LA for which nonpoint source controls need to be implemented. Therefore, EPA's guidance provides that a TMDL developed under the phased approach should include a monitoring plan that describes the additional data to be collected to determine if the load reductions required by the TMDL lead to attainment of water quality standards.

The monitoring recommendations suggest an agreement between the state's Regional Water Quality Control Board and Redwood National Park (and possibly other agencies) to jointly develop and implement a monitoring plan. It is anticipated that the monitoring plan will coordinate existing monitoring efforts within the watershed.

The monitoring plan will distinguish different monitoring needs for different stream types and hillslope locations. Priorities for monitoring tributaries and main stem reaches with spawning/rearing habitat should include

- Pebble counts at riffle crests
- Large woody debris inventories
- Thalweg and cross section measures
- Suspended sediment and possible bedload sediment at mouths of key tributaries
- Bulk sampling of substrate composition at riffle crests at a subset of established sites

Priorities for monitoring in the larger portions of Redwood Creek should include

- Thalweg profiles and cross sections
- Large woody debris inventories
- Suspended and bedload suspended sediment

Additional indicators that should be considered for monitoring programs include

- Substrate permeability
- Turbidity
- Bed mobility measures

Hillslope monitoring should provide adequate information to update the sediment budget every 10 to 15 years. All monitoring plans should include detailed descriptions of the monitoring protocols and data management efforts.

Implementation Plans

On August 8, 1997, Bob Perciasepe issued a memorandum, "New Policies for Establishing and Implementing Total Maximum Daily Loads (TMDLs)," which directs EPA regions to work in partnership with states to achieve nonpoint source load allocations established for 303(d)-listed waters impaired solely or primarily by nonpoint sources. To this end, the memorandum asks that regions assist states in developing implementation plans that include reasonable assurances that the nonpoint source load allocations established in TMDLs for waters impaired solely or primarily by nonpoint sources will in fact be achieved; a public participation process; and recognition of other relevant watershed management processes. Although implementation plans are not approved by EPA, they help establish the basis for EPA's approval of TMDLs.

Reasonable Assurances

EPA guidance calls for reasonable assurances when TMDLs are developed for waters impaired by both point and nonpoint sources or for waters impaired solely by nonpoint sources. In a water impaired by both point and nonpoint sources, where a point source is given a less stringent wasteload allocation based on an assumption that nonpoint source load reductions will occur, reasonable assurance must be provided for the TMDL to be approvable. This information is necessary for EPA to review the load and wasteload allocations required by the regulation.

In a water impaired solely by nonpoint sources, reasonable assurances are not required for a TMDL to be approvable. For such nonpoint source-only waters, states are encouraged to provide reasonable assurances regarding achievement of load allocations in the implementation plans described in section 7, above. As described in the August 8, 1997, Perciasepe memorandum, such reasonable assurances should be included in state implementation plans and "may be non-regulatory, regulatory, or incentive-based, consistent with applicable laws and programs."

References

USEPA. 1998. *Redwood Creek Sediment Total Maximum Daily Load*. U.S. Environmental Protection Agency, Region 9, Water Division, San Francisco, CA.

Contact: Dave Smith, Region 9 TMDL Coordinator
United States Environmental Protection Agency
75 Hawthorne Street • San Francisco, CA 94105
(415) 744-2012 • smith.davidw@epa.gov

References

Note: This bibliography includes references cited in the protocol and other selected references. EPA is currently developing a more extensive annotated bibliography of references concerning sediment water quality analysis and management, which will be made available under separate cover.

Berg, N.H., K.B. Roby, and B.J. McGurk. 1996. Cumulative watershed effects: Applicability of available methodologies to the Sierra Nevada. In Vol. III, *Assessments, commissioned reports, and background information, Sierra Nevada Ecosystem Project: Final report to Congress.* University of California, Davis, Centers for Water and Wildland Resources.

Bisson, P.A., G.H. Reeves, R.E. Bilby, and R J. Naiman. 1997. Watershed management and Pacific salmon: Desired future conditions. In *Pacific salmon and their ecosystems—Status and future options*, ed. Stouder, Bisson, and Naiman. Chapman and Hall, New York.

Black, 1991. *Watershed Hydrology.* Englewood Cliffs, New Jersey

California Department of Fish and Game. 1994. *Coho salmon habitat impacts—Qualitative assessment technique for registered professional foresters.* Draft no. 2, November 1994.

California Department of Forestry. 1990. *Forest practice rules, technical rule addendum No. 1.*

Chapman, D.W., and K.P. McLeod. 1987. *Development of criteria for fine sediment in the Northern Rockies Ecoregion.* EPA 910/9-87-162. U.S. Environmental Protection Agency, Washington, DC.

Clarke, C.D., and P.G. Waldo. 1986. Sediment yield from small and medium watersheds. In *Proceedings of the Fourth Interagency Sedimentation Conference*, pp. 3-19 to 3-28.

Davenport, T.E. 1983. *Soil erosion and transport dynamics in the Blue Creek Watershed, Pike County, Illinois.* IEPA/WPC/83/004. Illinois Environmental Protection Agency.

Dietrich, W.E., J.W. Kirchner, H. Ikeda, and F. Iseya, 1989, Sediment supply and the development of the coarse surface layer in gravel-bedded rivers, Nature, v.340, no. 6230, p. 215-217.

Dietrich, W.E., C.J. Wilson, D.R. Montgomery, J. McKean, and R. Beaver. 1992. Erosion thresholds and land surface morphology. *Geology* 20:675-79.

Dietrich, W.E., C.J. Wilson, D.R. Montgomery, and J. McKean 1993. Analysis of erosion thresholds, channel networks, and landscape morphology using a digitized terrain. *Journal of Geology* 101(2):259-78.

Dissmeyer, G.E. 1994. *Evaluating the effectiveness of forestry best management practices in meeting water quality goals or standards.* U.S. Forest Service Miscellaneous Publication 1520. U.S. Department of Agriculture Forest Service, Washington, DC.

Dunne, T., and L.B. Leopold. 1978. *Water in environmental planning.* W.H. Freeman and Co., San Francisco, CA.

Endicott, C.L., and T.E. McMahon. 1996. *Development of a TMDL to reduce nonpoint source sediment pollution in Deep Creek, Montana.* Report to Montana Department of Environmental Quality.

Gomez, B., and M. Church. 1989. An assessment of bed load sediment transport formulae for gravel bed rivers. *Water Resources Research* 25(6):1161-1186.

Ketcheson, G.L. 1986. *Sediment rating equations: An evaluation for streams in the Idaho Batholith.* Intermountain Research Station General Technical Report INT-213. U.S. Department of Agriculture Forest Service, Ogden, UT.

Knopp, C. 1993. *Testing indices of cold water fish habitat.* California North Coast Regional Water Quality Control Board, Santa Rosa, CA.

Kondolf, G.M. 1995. Geomorphological stream classification in aquatic habitat classification: Uses and limitations. *Aquatic Conservation* 5:27-141.

AR0023104

Lewis and Rice. 1989. *Critical sites erosion study.* Vol. II. *Site conditions related to erosion on private timberlands in Northern California*. Report of a cooperative investigation by the California Department of Forestry and U.S. Forest Service PSW Forest and Range Experiment Station.

Lewis and Rice. 1990. Estimating erosion risk on forest lands using improved methods of discriminant analysis. *Water Resources Research* 26(8):1721-33.

Limno-Tech, Inc. 1993. *Silver Creek, AZ demonstration TMDL*. Prepared for U.S. Environmental Protection Agency, Region 9.

Lisle, T., and S. Hilton. 1992. The volume of fine sediment in pools: An index of sediment supply in gravel-bed streams. *Water Resources Bulletin* 28(2):371-383.

Louisiana-Pacific Corporation. 1996. *Watershed analysis manual*. Samoa, CA.

MacDonald, L. 1992. Sediment monitoring: Reality and hope. Presented at EPA/USFS Technical Workshop on Sediments, February 3-7, 1992, Corvallis, OR.

MacDonald, L., A.W. Smart, and R.C. Wissmar. 1991. *Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska*. EPA 910/9-91-001. U.S. Environmental Protection Agency, Region 10, Nonpoint Source Section, Seattle, WA.

McGurk, B.J., and D.R. Fong. 1995. Equivalent roaded area as a measure of cumulative effect of logging. *Environmental Management* 19(4):609-621.

McMahon, T.E. 1983. *Habitat suitability index models: Coho salmon*. FWS/OBS-82/10.49. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC.

Miller, J.R., and J.B. Ritter. 1996. An examination of the Rosgen classification of natural rivers. *Catena* 27:295-99.

Montgomery, D.R., and W.A. Dietrich. 1994. A physically based model for the topographic control on shallow landsliding. *Water Resources Research* 30:1153-71.

Naiman, R.J., and R.E. Bilby.1998. *River ecology and management*. Springer-Verlag New York, Inc.

Ohlander, C.A. 1991. *Water resources analysis: T-Walk—water quality monitoring field manual and tables*. U.S. Department of Agriculture Forest Service, Region 2.

Peterson, N.P., A. Henry, and T.P. Quinn. 1992. *Assessment of cumulative effects on salmonid habitat: Some suggested parameters and target condition*. Prepared for the Washington Department of Natural Resources and The Coordinated Monitoring, Evaluation and Research Committee, Timber Fish and Wildlife Agreement. March 2.

Phillip Williams Associates. 1996. *Garcia river gravel management plan*. San Francisco, CA.

Platts, W. S. 1990. *Managing fisheries and wildlife on rangelands grazed by livestock.* Nevada Department of Wildlife, Reno, NV.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. *Methods for evaluating stream, riparian, and biotic conditions.* General Technical Report INT-183. U.S. Department of Agriculture, Forest Service, Ogden, UT.

Regional Ecosystem Office. 1995. *Ecosystem analysis at the watershed scale.* Version 2.2. U.S. Government Printing Office: 1995-689-120/21215. Regional Ecosystem Office, Portland, OR.

Reid, M. 1996. *Evaluating timber management effects on land uses and values in Northwest California*. Draft, December 3.

Reid, M. 1997. *Comparative analysis of watershed analysis methods for TMDL analysis*. Draft, May 1997.

Reid, L.M., and T. Dunne. 1996. *Rapid evaluation of sediment budgets.* Catena Verlag, Reiskirchen, Germany.

Reiser, D.W., and T.C. Bjornn. 1979. 1. Habitat requirements of anadromous salmonids. In *Influence of* *forest and rangeland management of anadromous fish habitat in the western United States and Canada,* ed. W.R. Meehan. General Technical Report PNW-96. U.S. Department of Agriculture Forest Service.

Reiser, D.W., and J.B. Bradley. 1992. Fine sediment intrusion and salmonid habitat. In *Advances in hydro-science and engineering*, Vol. 1., ed. Sam S.Y. Yang.

Renard, K.G., G.R. Fpster, G.A. Weesies, D.K. McCool, and D.C. Yoder, coordinators. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook No. 703, 404 pp.

Rosenburg, D.M., and V.H.Resch. 1993. *Freshwater biomonitoring and benthic macroinvertebrates.* Chapman & Hull, New York.

Rosgen, D. 1996. *Applied river morphology.* Wildland Hydrology Books, Pagosa Springs, CO.

Satterlund D.R., and P.W. Adams, 1993. *Wildland Watershed Management*. 2nd edition. New York.

Spence, B.C., G.A. Lomnicky, R.M. Hughes, and R.P. Novitzki. 1996. *An ecosystem approach to salmonid conservation*. TR-4501-96-6057. ManTech Environmental Research Services, Corp. National Marine Fisheries Service, Portland, OR.

USDA Agricultural Research Service. 1975. Present and prospective technology for predicting sediment yield and sources. In *Proceedings, Sediment Yield Workshop*. 1972. Oxford, MS.

USDA Forest Service. 1988. Cumulative off-site watershed effects analysis. In *USDA Forest Service Region 5 soil and water conservation handbook.* FSH 2509.22. U.S. Department of Agriculture Forest Service, San Francisco, CA.

USDA Forest Service, PSW Region. 1996. *Stream condition inventory protocol version 3.4.* Draft, June 27, 1996.

USDOI-BLM. 1993/1995. *Process for assessing proper functioning condition.* TR1737-9. Revised 1995. U.S. Department of the Interior, Bureau of Land Management, Washington, DC.

USDOI-BLM. 1995. *Mainstem Trinity River Watershed analysis.* U.S. Department of the Interior, Bureau of Land Management, Washington, DC.

USEPA. 1989. *Rapid bioassessment protocols for use in streams and rivers: Benthic macroinvertebrates and fish.* EPA/444/4-89-001. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1991a. *Guidance for water quality-based decisions: The TMDL process.* EPA 440/4-91-001. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1991b. *Technical support document for water quality-based toxics control.* EPA/505/2-90-001. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1992a. *TMDL case study: Sycamore Creek, Michigan.* EPA841-F-92-012. U.S. Environmental Protection Agency, Office of Water, Assessment and Watershed Protection Division, Washington, DC.

USEPA. 1992b. *TMDL case study: South Fork of the Salmon River, Idaho.* U.S. Environmental Protection Agency, Office of Water, Assessment and Watershed Protection Division, Washington, DC.

USEPA. 1992c. *Monitoring guidance for the National Estuary Program.* EPA 842 B-92-004. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1993. *Guidance specifying management measures for sources of nonpoint source pollution in coastal waters.* EPA 840-B-92-002. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1994a. *EPA requirements for quality assurance project plans for environmental data operations.* EPA QA/R-5. Draft interim final, August 1994. U.S. Environmental Protection Agency, Quality Assurance Management Staff, Washington, DC.

USEPA. 1994b. *Guidance for the data quality objectives process.* EPA QA/G-4. EPA/600/R-96/055. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.

USEPA. 1995a. *Watershed protection: A statewide approach.* EPA 841-R-95-001. U.S. Environmental Protection Agency, Washington DC.

USEPA. 1995b. *Watershed protection: A project focus.* EPA 841-R-95-003. U.S. Environmental Protection Agency, Washington DC.

USEPA. 1996a. *TMDL development cost estimates: Case studies of 14 TMDLs.* EPA-R-96-001. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1996b. *Watershed approach framework.* EPA-840-5-96-001. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1996c. *Chalk Creek Watershed project implementation plan—Continuation project summary sheet, 1996.* U.S. Environmental Protection Agency, Region 8, Denver, CO.

USEPA. 1996d. *Nonpoint source monitoring and evaluation guide.* Draft final, November 1996. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

USEPA. 1997a. New policies for establishing and implementing Total Maximum Daily Loads (TMDLs). U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1997b. *Linear regression for nonpoint source pollution analysis.* EPA-841-B-97-007. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1997c. *Compendium of tools for watershed assessment and TMDL development.* EPA 841-B-97-006. U.S. Environmental Protection Agency, Washington, DC.

USEPA 1998. Redwood Creek Sediment Total Maximum Daily Load. US Environmental Protection Agency, Region 9, Water Division, San Francisco, CA.

USEPA 1999. Draft Guidance for Water Quality-based Decisions: The TMDL Process (Second Edition). EPA 841-D-99-001. U.S. Environmental Protection Agency, Washington, DC.

Vanoni, V.A., ed. 1975. *Sedimentation engineering.* American Society of Civil Engineers, New York, NY.

Van Sickle, J., and R.L. Beschta. 1983. Supply-based models of suspended sediment transport in streams. *Water Resources Research* 19(3):768-778.

Washington Forest Practices Board. 1994. *Standard methodology of conducting watershed analysis under chapter 222-22 WAC.* Version 2.1, November 1994. Washington Forest Practices Board, Olympia, WA.

Waters, T.F. 1995. *Sediment in streams—Sources, biological effects, and control.* American Fisheries Society Monograph 7. American Fisheries Society, Bethesda, MD.

Weaver, W., and D. Hagans. 1996. Sediment treatments and road restoration: Protecting and restoring watersheds from sediment-related impacts. In *Healing the watershed—A guide to the restoration of watersheds and native fish in the west.* Pacific Rivers Council, Inc.

White, W.R., H. Milli, and A.D. Crabbe. 1978. *Sediment transport: An appraisal of available methods.* UK Hydraulics Research Station Report 119. Hydraulics Research Station, Wallingford, UK.

Wolman, M.G., and J.P. Miller. 1960. Magnitude and frequency of forces in geomorphic processes. *Journal of Geology* 68:54-74.

Young, M.K., et al. 1991. Selection of measures of substrate composition to estimate survival to emergence of salmonids and to detect changes in stream substrate. *North American Journal of Fisheries Management* 11:339-346.

KEY TO ACRONYMS

AGNPS	Agricultural Nonpoint Source Pollution Model
ANSWERS	Areal Nonpoint Source Watershed Environment Response Simulation
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BLM	Bureau of Land Management
BMP	best management practice
CFR	Code of Federal Regulations
CREAMS	Chemical, Runoff, and Erosion from Agricultural Management Systems
CSES	Critical Sites Erosion Study
CWA	Clean Water Act
DR3M	Multi-Event Urban Runoff Quality Model
D50	diameter of 50th percentile particle found through stream substrate sampling
EMAP	Environmental Monitoring and Assessment Program
ERA	equivalent roaded acreage
FEMAT	Federal Ecosystem Management Team
GIS	Geographic Information System
GWLF	Generalized Watershed Loading Functions
HSPF	Hydrologic Simulation Program-Fortran
LA	load allocation (for nonpoint sources in TMDLs)
MOS	margin of safety, a required TMDL element
NAWQUA	National Water Quality Assessment project led by USGS
NPDES	National Pollutant Discharge Elimination System
NPS	nonpoint source
NRCS	Natural Resource Conservation Service
NTU	nephelometric turbidity units
PL-566	Public Law 566, which established the USDA Small Watersheds program
QA/QC	quality assurance/quality control
RBP	rapid bioassessment protocol
RUSLE	revised universal soil loss equation
SWAT	Soil Water Assessment Tool
SWMM	Storm Water Management Model
SWRRBWQ	Simulator for Water Resources in Rural Basins- Water Quality
TMDL	total maximum daily load
TSS	total suspended solids or sediment
USDA	United States Department of Agriculture
USDOI	United States Department of the Interior
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geological Survey
USLE	universal soil loss equation
V*	measure of residual pool volume occupied by fine sediments
WLA	waste load allocation (for point sources in TMDLs)
WQS	water quality standards
WRENSS	Water Resources Evaluation of Non-point Silvicultural Sources

GLOSSARY

Acute toxicity. A chemical stimulus severe enough to rapidly induce an effect; in aquatic toxicity tests, an effect observed within 96 hours or less is considered acute. When referring to aquatic toxicology or human health, an acute effect is not always measured in terms of lethality.

Adaptive management. Approach where source controls are initiated while additional monitoring data are collected to provide a basis for future review and revision of the TMDL (as well as management activities).

Adsorption-desorption. Adsorption is the process by which nutrients such as inorganic phosphorous adhere to particles via a loose chemical bond with the surface of clay particles. Desorption is the process by which inorganic nutrients are released from the surface of particles back into solution. Adsorption differs from absorption in that absorption is the assimilation or incorporation of a gas, liquid, or dissolved substance into another substance.

Advanced secondary treatment. Biological or chemical treatment processes added to a secondary treatment plant including a conventional activated sludge to increase the removal of solids and BOD. Typical removal rates for advanced secondary plants are on the order of 90 percent removal of solids and BOD.

Advanced waste treatment (AWT). Wastewater treatment process that includes combinations of physical and chemical operation units designed to remove nutrients, toxic substances, or other pollutants. Advanced, or tertiary, treatment processes treat effluent from secondary treatment facilities using processes such as nutrient removal (nitrification, denitrification), filtration, or carbon adsorption. Tertiary treatment plants typically achieve about 95 percent removal of solids and biochemical oxygen demand (BOD) in addition to removal of nutrients or other materials.

Advection. Bulk transport of the mass of discrete chemical or biological constituents by fluid flow within a receiving water. Advection describes the mass transport due to the velocity, or flow, of the waterbody.

Aerobic. Environmental conditions characterized by the presence of dissolved oxygen; used to describe biological or chemical processes that occur in the presence of oxygen.

Aggradation. The raising of the bed of a watercourse by the deposition of sediment.

Allocations. That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background source. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)

Alluvium. Sediment deposited by flowing water, such as in a riverbed, floodplain, or delta.

Ambient water quality. Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact to human health.

Anadromous. Migrating up rivers from the sea to breed in fresh water.

Anaerobic. Environmental condition characterized by zero oxygen levels. Describes biological and chemical processes that occur in the absence of oxygen.

Anoxic. Aquatic environmental conditions containing zero or little dissolved oxygen. See also anaerobic.

Anthropogenic. Pertains to the [environmental] influence of human activities.

Anti-degradation Policies. Policies that are part of each state's water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that may impact the integrity of waterbodies.

Aquatic classification system. Assigns a classification to a waterbody reflecting the water quality and the biological health (integrity). Classification is determined through use of biological indices (see IBI). Examples of classifications include oligosaprobic (cleanest water quality) and polysaprobic (highly polluted water).

Aquatic ecosystem. Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.

Assimilative capacity. The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.

Background levels. Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources). A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

Bedload sediment. Portion of sediment load transported downstream by sliding, rolling, bouncing along the channel bottom. Generally consists of particles >1 mm.

Benthic. Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody.

Benthic organisms. Organisms living in, or on, bottom substrates in aquatic ecosystems.

Best management practices (BMPs). Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Bioaccumulation. The process by which a compound is taken up by an aquatic organism, both from water and through food.

Bioassessment. Biological assessment; the evaluation of an ecosystem using integrated assessments of habitat and biological communities in comparison to empirically defined reference conditions.

Bioavailability. A measure of the physicochemical access that a toxicant has to the biological processes of an organism. The less the bioavailability of a toxicant, the less its toxic effect on an organism.

Biochemical oxygen demand (BOD). The amount of oxygen per unit volume of water required to bacterially or chemically oxidize (stabilize) the oxidizable matter in water. Biochemical oxygen demand measurements are usually conducted over specific time intervals (5, 10, 20, 30 days). The term BOD generally refers to a standard 5-day BOD test.

Biological criteria. Also known as biocriteria, biological criteria are narrative expressions or numeric values of the biological characteristics of aquatic communities based on appropriate reference conditions. Biological criteria serve as an index of aquatic community health.

Biomass. The amount, or weight, of a species, or group of biological organisms, within a specific volume or area of an ecosystem.

Boundary conditions. Values or functions representing the state of a system at its boundary limits.

Calcareous. Pertaining to or containing calcium carbonate.

Calibration. The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.

Carbonaceous. Pertaining to or containing carbon derived from plant and animal residues

Cation exchange capacity. The sum total of exchangeable cations that a soil can adsorb. Expressed in centimoles per kilogram of soil (or of other adsorbing material such as clay.)

Channel. A natural stream that conveys water; a ditch or channel excavated for the flow of water.

Channel improvement. The improvement of the flow characteristics of a channel by clearing, excavation, realignment, lining, or other means in order to increase its capacity. Sometimes used to connote channel stabilization.

Channel stabilization. Erosion prevention and stabilization of velocity distribution in a channel using jetties, drops, revetments, vegetation, and other measures.

Chloride. An atom of chlorine in solution; an ion bearing a single negative charge.

Chronic toxicity. Toxicity impact that lingers or continues for a relatively long period of time, often one-tenth of the life span or longer. Chronic effects could include mortality, reduced growth, or reduced reproduction.

Clean sediment. Sediment that is not contaminated by chemical substances. Pollution caused by clean sediment refers to the quantity of sediment, as opposed to the presence of pollutant-contaminated sediment.

Clean Water Act (CWA). The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is section 303(d), which establishes the TMDL program.

Coastal Zone. Lands and waters adjacent to the coast that exert an influence on the uses of the sea and its ecology, or whose uses and ecology are affected by the sea.

Colluvium. Soil and rock debris on a hillslope that has been transported from its original location.

Completely mixed condition. A condition in which no measurable difference in the concentration of a pollutant exists across a transect of the waterbody (e.g., the concentration does not vary by 5 percent).

Concentration. Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).

Concentration-based limit. A limit based on the relative strength of a pollutant in a wastestream, usually expressed in milligrams per liter (mg/L).

Conservative substance. A substance that does not undergo any chemical or biological transformation or degradation in a given ecosystem.

Contamination. The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.

Continuous discharge. A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities.

Conventional pollutants. As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.

Cost-share program. A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs are paid by the producer.

Cross-sectional area. Wet area of a waterbody normal to the longitudinal component of the flow.

Critical condition. The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.

Cryptosporidium. See protozoa.

Decay. The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.

Decomposition. Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. (See also, **Respiration**.)

Design stream flow. The stream flow used to conduct steady-state wasteload allocation modeling.

Designated uses. Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.

Deterministic model. A model that does not include built-in variability: same input will always equal the same output.

Detritus. Any loose material produced directly from disintegration processes. Organic detritus consists of material resulting from the decomposition of dead organic remains.

Diagenesis. Production of sediment fluxes as a result of the flux of particulate organic carbon in the sediment and its decomposition. The diagenesis reaction can be thought of as producing oxygen equivalents released by various reduced species.

Diel ("die´-el"). Involving a 24-hour period.

Dilution. The addition of some quantity of less concentrated liquid (water) that results in a decrease in the original concentration.

Direct runoff. Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.

Discharge. Flow of surface water in a stream or canal or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.

Discharge Monitoring Report (DMR). Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.

Discharge permits (NPDES). A permit issued by the U.S. EPA or a State regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. It is called the NPDES because the permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.

Dispersion. The spreading of chemical or biological constituents, including pollutants, in various directions from a point source, at varying velocities depending on the differential in-stream flow characteristics.

Dissolved oxygen (DO). The amount of oxygen that is dissolved in water. This term also refers to a measure of the amount of oxygen available for biochemical activity in a waterbody, and is an indicator of the quality of that water.

Dissolved oxygen sag. Longitudinal variation of dissolved oxygen representing the oxygen depletion and recovery following a waste load discharge into a receiving water.

Diurnal. Actions or processes having a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and which recur every 24 hours.

Domestic wastewater. Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.

Drainage basin. A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.

Dry ravel. Sloughing of sediment due to loss of cohesion in surface materials.

Dynamic model. A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.

Dynamic simulation. Modeling of the behavior of physical, chemical, and/or biological phenomena and their variation over time.

Ecoregion. A physical region that is defined by its ecology, which includes meteorological factors, elevation, plant and animal speciation, landscape position, and soils.

Ecosystem. An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.

Effluent. Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.

Effluent guidelines. Technical EPA documents that set effluent limitations for given industries and pollutants.

Effluent limitation. Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.

Effluent plume. Delineates the extent of contamination in a given medium as a result of a distribution of effluent discharges (or spills). Usually shows the concentration gradient within the delineated areas or plume of flow of contaminants.

Embeddedness. The degree to which fine sediments fill the spaces (interstices) between rocks on the substrate.

Empirical model. Use of statistical techniques to discern patterns or relationships underlying observed or measured data for large sample sets. Does not account for physical dynamics of waterbodies.

Endpoint. An endpoint (or indicator/target)is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).

Enhancement. In the context of restoration ecology, any improvement of a structural or functional attribute.

Enteric. Of or within the gastrointestinal tract.

Environmental Monitoring and Assessment Program (EMAP). A USEPA program to monitor and assess the ecological health of major ecosystems, including surface waters, forests, near-coastal waters, wetlands, agricultural lands, arid lands, and the Great Lakes, in an integrated, systematic manner. Although EMAP has been curtailed somewhat during recent years, the program is designed to operate at regional and national scales, for decades, and to evaluate the extent and condition of entire ecological resources by using a common sampling framework to sample approximately 12,500 locations in the conterminous United States.

Epiphyte. A plant growing on another plant; more generally, any organism growing attached on a plant.

Estuary. Brackish-water areas influenced by the tides where the mouth of a river meets the sea.

Estuarine number. A nondimensional parameter accounting for decay, tidal dispersion, and advection velocity; used for classification of tidal rivers and estuarine systems.

Existing use. Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).

Fate of pollutants. Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.

Feedlot. A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.

First-order kinetics. The type of relationship describing a dynamic reaction in which the rate of transformation of a pollutant is proportional to the amount of that pollutant in the environmental system.

Flocculation. The process by which suspended colloidal or very fine particles are assembled into larger masses or floccules that eventually settle out of suspension.

Fluvial geomorphology. The effect of rainfall and runoff on the form and pattern of riverbeds and river channels.

Flux. Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.

Forcing functions. External empirical formulation used to provide input describing a number of processes. Typical forcing functions include parameters such as temperature, point and tributary sources, solar radiation, and waste loads and flow.

Fry. Young, newly hatched fish.

Geochemical. Referring to chemical reactions involving earth materials such as soil, rocks, and water.

Geomorphology. The study of the evolution and configuration of landforms.

Gradient. The rate of change of the value of one quantity with respect to another; for example, the rate of decrease of temperature with depth in a lake.

Ground water. The supply of fresh water found beneath the earth's surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.

Gully erosion. The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil form this narrow area to considerable depths, ranging from 1-2 feet to as much as 75-100 feet.

Half-saturation constant. Nutrient concentration at which the growth rate of a population of a species or group of species is half the maximum rate. Half-saturation constants define the nutrient uptake characteristics of different phytoplankton species. Low half-saturation constants indicate the ability of the algal group to thrive under nutrient-depleted conditions.

Heterotroph. An organism that uses organic carbon for the formation of its cell tissue, e.g., is unable to synthesize organic compounds from inorganic substrates for food and must consume organisms or their products. Bacteria are examples of heterotrophs; photosynthesizing organisms are not.

Hillslope Targets. Quantitative measure that links the upslope sources of sediment and instream impacts of sediment discharge.

Hydrodynamic model. Mathematical formulation used in describing fluid flow circulation, transport, and deposition processes in receiving water.

Hydrograph. A graph showing variation of in stage (depth) or discharge of water in a stream over a period of time.

Hydrologic cycle. The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.

Hydrology. The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.0

Hydrolysis. A chemical reaction that occurs between a substance and water resulting in the cleaving of a molecular bond and the formation of new bonds with components of the decomposed water molecule; a reaction of water with a salt to create an acid or a base.

Hyetograph. Graph of rainfall rate during a storm event.

Hypolimnetic oxygen depletion rate. The hypolimnetic oxygen depletion rate describes changing dissolved oxygen concentrations in the hypolimnion (lowest stratum) of lakes and reservoirs. Dissolved oxygen concentrations in the hypolimnion are especially significant because of their effect on fish.

Index of Biotic Integrity (IBI). The IBI uses measurements of the distribution and abundance or absence of several fish species types in each waterbody for comparison. A portion of a waterbody is compared to a similar, unimpacted waterbody in the same ecoregion.

Indicator. A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.

Indirect discharge. A nondomestic discharge introducing pollutants to a publicly owned treatment works.

Infiltration capacity. The capacity of a soil to allow water to infiltrate into or through it during a storm.

Initial mixing zone. The region immediately downstream of an outfall where effluent dilution processes occur. Because of the combined effects of the effluent buoyancy, ambient stratification, and current, the prediction of initial dilution can be complex.

In situ. In place; in situ measurements consist of measurements of components of processes in a full-scale system or a field, rather than in a laboratory.

Interstitial water. Water contained in the interstices, which are the pore spaces or voids in soils and rocks, i.e., ground water.

Irrigation. Applying water or wastewater to land areas to supply the water and nutrient needs of plants.

Irrigation return flow. Surface and subsurface water that leaves a field after the application of irrigation water.

Karst geology. Solution cavities and closely-spaced sinkholes formed as a result of dissolution of carbonate bedrock.

Kinetic processes. Description of the rates and modes of changes in the transformation or degradation of a substance in an ecosystem.

Land application. Discharge of wastewater onto the ground for treatment or reuse. (See: irrigation)

Leachate. Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers. Leaching can occur in farming areas, feedlots, and landfills, and can result in hazardous substances entering surface water, groundwater, or soil.

Leachate collection system. A system that gathers leachate and pumps it to the surface for treatment.

Light saturation. The optimal light level for algae and macrophyte growth and photosynthesis.

Loading, Load, Loading rate. The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.

Load allocation (LA). The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished. (40 CFR 130.2(g))

Loading capacity (LC). The greatest amount of loading that a water can receive without violating water quality standards.

Longitudinal dispersion. The spreading of chemical or biological constituents, including pollutants, downstream from a point source at varying velocities due to the differential in-stream flow characteristics.

Low-flow (7Q10). Low-flow (7Q10) is the 7-day average low flow occurring once in 10 years; this probability-based statistic is used in determining stream design flow conditions and for evaluating the water quality impact of effluent discharge limits.

Margin of Safety (MOS). A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).

Mass balance. An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.

Mass loading. The quantity of a pollutant transported to a waterbody.

Mass wasting. Downslope transport of soil and rocks due to gravitational stress.

Mathematical model. A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the one, or more, individual processes and interactions within some prototype aquatic ecosystem. A mathematical water quality model is used as the basis for waste load allocation evaluations.

Maximum depth. The greatest depth of a waterbody.

Mean depth. Volume of a waterbody divided by its surface area.

Mineralization. The transformation of organic matter into a mineral or an inorganic compound.

Mitigation. Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those which restore, enhance, create, or replace damaged ecosystems.

Monitoring. Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.

Monte Carlo simulation. A stochastic modeling technique that involves the random selection of sets of input data for use in repetitive model runs. Probability distributions of receiving water quality concentrations are generated as the output of a Monte Carlo simulation.

Narrative criteria. Nonquantitative guidelines that describe the desired water quality goals.

National Pollutant Discharge Elimination System (NPDES). The national program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under Sections 307, 402, 318, and 405 of the Clean Water Act.

Natural waters. Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.

Nonpoint source. Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Numeric target. A measurable value determined for the pollutant of concern which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.

Numerical model. Model that approximates a solution of governing partial differential equations which describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.

One-dimensional model (1-D). A mathematical model defined along one spatial coordinate of a natural water system. Typically 1-D models are used to describe the longitudinal variation of water quality constituents along the downstream direction of a stream or river. In writing the model, it is assumed that the cross-channel (lateral) and vertical variability is relatively homogenous and can, therefore, be averaged over those spatial coordinates.

Organic matter. The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substance synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.

Outfall. The point where water flows from a conduit, stream, or drain.

Oxidation. The chemical union of oxygen with metals or organic compounds accompanied by a removal of hydrogen or another atom. It is an important factor for soil formation and permits the release of energy from cellular fuels.

Oxygen demand. Measure of the dissolved oxygen used by a system (microorganisms) in the oxidation of organic matter. (See also **Biochemical oxygen demand**.)

Oxygen depletion. A deficit of dissolved oxygen in a water system due to oxidation of organic matter.

Oxygen saturation. The natural or artificial reaeration or oxygenation of a water system (water sample) to bring the level of dissolved oxygen to maximum capacity. Oxygen saturation is greatly influenced by temperature and other water characteristics.

Partition coefficient. A constant symbolizing the ratio of the concentration of a solute in the upper of two phases in equilibrium to its concentration in the lower phase. Chemicals in solution are partitioned into dissolved and particulate adsorbed phase based on their corresponding sediment-to-water partitioning coefficient.

Pathogen. Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

Peak runoff. The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.

Periphyton. Microscopic underwater plants and animals that are firmly attached to solid surfaces such as rocks, logs, pilings, and other structures.

Permit. An authorization, license, or equivalent control document issued by EPA or an approved Federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.

Permit Compliance System (PCS). Computerized management information system which contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.

Phased approach. Under the phased approach to TMDL development, LAs and WLAs are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.

Point source. Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollutant. Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water. (CWA Section 502(6)).

Pollution. Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Pool. Portion of a stream with reduced current velocity, often with deeper water than surrounding areas ans with a smooth surface.

Postaudit. A subsequent examination and verification of model predictive performance following implementation of an environmental control program.

Pretreatment. The treatment of wastewater to remove or reduce contaminants prior to discharge into another treatment system or a receiving water.

Primary productivity. A measure of the rate at which new organic matter is formed and accumulated through photosynthesis and chemosynthesis activity of producer organisms (chiefly, green plants). The rate of primary production is estimated by measuring the amount of oxygen released (oxygen method) or the amount of carbon assimilated by the plant (carbon method).

Primary treatment. A basic wastewater treatment method that uses settling, skimming, and (usually) chlorination to remove solids, floating materials, and pathogens from wastewater. Primary treatment typically removes about 35 percent of biochemical oxygen demand (BOD) and less than half of the metals and toxic organic substances.

Privately owned treatment works. Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a POTW.

Protozoa. A phylum or subkingdom including all single-celled animals with membrane- bound organelles; they may be aquatic or parasitic, with or without a test, solitary or colonial, sessile or free-swimming, moving by cilia, flagella, or pseudopodia.

Public comment period. The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g., a *Federal Register* notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).

Publicly owned treatment works (POTW). Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.

Raw sewage. Untreated municipal sewage.

Reaction rate coefficient. A constant describing the rate of transformation of a substance in an environmental medium characterized by a set of physical, chemical, and biological conditions such as temperature and dissolved oxygen level.

Reaeration. The net flux of oxygen occurring from the atmosphere to a body of water with a free surface.

Receiving waters. Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.

Redd. Nest made in gravel, consisting of a depression hydraulically dug by a fish for egg deposition (and then filled) and the associated gravel mounds.

Reference sites. Waterbodies that are representative of the characteristics of the region and subject to minimal human disturbance.

Reserve capacity. Pollutant loading rate set aside in determining stream waste load allocation accounting for uncertainty and future growth.

Residence time. Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.

Restoration. Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.

Riffle. A rocky shoal or sand bar located just below the surface of the water.

Rill erosion. An erosion process in which numerous small channels of only several centimeters in depth are formed; occurs mainly on recently cultivated soils.

Riparian areas. Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.

Riparian vegetation. Hydrophytic vegetation growing in the immediate vicinity of a lake or river closely enough so that its annual evapotranspiration constitutes a factor in the lake or river regime.

Riparian zone. The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.

Roughness coefficient. A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.

Rotating biological contactor (RBC). A wastewater treatment process consisting of a series of closely spaced rotating circular disks of polystyrene or polyvinyl chloride. Attached biological growth is promoted on the surface of the disks. The rotation of the disks allows contact with the wastewater and the atmosphere to enhance oxygenation.

Runoff. That part of precipitation, snow melt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Scoping modeling. A method of approximation that involves simple, steady-state analytical solutions for a rough analysis of a problem.

Scour. To abrade and wear away. Used to describe the weathering away of a terrace or diversion channel or streambed. The clearing and digging action of flowing water, especially the downward erosion by stream water in sweeping away mud and silt on the outside of a meander or during flood events.

Secondary treatment. The second step in most publicly owned waste treatment systems, in which bacteria consume the organic parts of the waste. It is accomplished by bringing together waste, bacteria, and oxygen in trickling filters or in the activated sludge process. This treatment removes floating and settleable solids and about 90 percent of the oxygen-demanding substances and suspended solids. Disinfection is the final stage of secondary treatment. (See **Primary treatment, Tertiary treatment**.)

Sediment. Particulate organic and inorganic matter that accumulates in a loose, unconsolidated form on the bottom of natural waters.

Sediment delivery. Contribution of transported sediment to a particular location or part of a landscape.

Sediment oxygen demand (SOD). The solids discharged to a receiving water are partly organics, and upon settling to the bottom, they decompose anaerobically as well as aerobically, depending on conditions. The oxygen consumed in aerobic decomposition represents another dissolved oxygen sink for the waterbody.

Sediment production. Delivery of colluvium or bedrock from hillslope to stream channel. The production rate is evaluated as the sum of the rates of colluvial bank erosion and sediment transport across channel banks.

Sediment yield. Amount of sediment passing a particular point (e.g., discharge point of the basin) in a watershed per unit of time.

Sedimentation. Process of deposition of waterborne or windborne sediment or other material; also refers to the infilling of bottom substrate in a waterbody by sediment (siltation).

Septic system. An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a system of tile lines or a pit for disposal of the liquid effluent (sludge) that remains after decomposition of the solids by bacteria in the tank; must be pumped out periodically.

Sewage fungus. Proliferations of bacteria and/or fungi that may form feathery, cotton-wool-like growths in streams and rivers that have high concentrations of dissolved organic compounds.

Sewer. A channel or conduit that carries wastewater and stormwater runoff from the source to a treatment plant or receiving stream. "Sanitary" sewers carry household, industrial, and commercial waste. "Storm" sewers carry runoff from rain or snow. "Combined" sewers handle both.

Sheet erosion. Also Sheetwash. Erosion of the ground surface by unconcentrated (i.e. not in rills) overland flow.

Sheetwash. Also Sheet erosion. Erosion of the ground surface by unconcentrated (i.e. not in rills) overland flow.

Simulation. The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Sinuosity. The degree to which a river or stream bends.

Slope. The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04); degrees (2 degrees 18 minutes), or percent (4 percent).

Sorption. The adherence of ions or molecules in a gas or liquid to the surface of a solid particle with which they are in contact.

Spatial segmentation. A numerical discretization of the spatial component of a system into one or more dimensions; forms the basis for application of numerical simulation models.

Stabilization pond. Large earthen basin used for the treatment of wastewater by natural processes involving the use of both algae and bacteria.

Steady-state model. Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations.

Stoichiometric ratio. Mass-balance-based ratio for nutrients, organic carbon and algae (e.g., nitrogen-to-carbon ratio).

STORET. U.S. Environmental Protection Agency (EPA) national water quality database for STORage and RETrieval (STORET). Mainframe water quality database that includes physical, chemical, and biological data measured in waterbodies throughout the United States.

Storm runoff. Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or waterbodies or is routed into a drain or sewer system.

Stratification (of waterbody). Formation of water layers each with specific physical, chemical, and biological characteristics. As the density of water decreases due to surface heating, a stable situation develops with lighter water overlaying heavier and denser water.

Streamflow. Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term streamflow is more general than "runoff" as streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

Stream restoration. Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream due to urbanization, farming, or other disturbance.

Stressor. Any physical, chemical, or biological entity that can induce an adverse response.

Substrate. Refers to bottom sediment material in a natural water system.

Surface area. The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.

Surface runoff. Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.

Surface water. All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.

Suspended solids or load. Organic and inorganic particles (sediment) suspended in and carried by a fluid (water). The suspension is governed by the upward components of turbulence, currents, or colloidal suspension. Suspended sediment usually consists of particles <0.1 mm, although size may vary according to current hydrological conditions. Particles between 0.1 mm and 1 mm may move as suspended or be deposited (bedload).

Technology-based limitations. Industry-specified effluent limitations applied to a discharge when it will not cause a violation of water quality standards at low stream flows. Usually applied to discharges into large rivers.

Technology-based standards. Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.

Temperature coefficient. Rate of increase in an activity or process over a 10 degree Celsius increase in temperature. Also referred to as the Q_{10}.

Tertiary treatment. Advanced cleaning of wastewater that goes beyond the secondary or biological stage, removing nutrients such as phosphorus, nitrogen, and most biochemical oxygen demand (BOD) and suspended solids.

Thalweg. Deepest part of a stream channel.

Three-dimensional model (3-D). Mathematical model defined along three spatial coordinates where the water quality constituents are considered to vary over all three spatial coordinates of length, width, and depth.

Topography. The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.

Total Maximum Daily Load (TMDL). The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Transit time. In nutrient cycles, the average time that a substance remains in a particular form; ratio of biomass to productivity.

Transport of pollutants (in water). Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) diffusion, or transport due to turbulence in the water.

Tributary. A lower order stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.

Turbidity. A measure of opacity of a substance; the degree to which light is scattered or absorbed by a fluid.

Turbulent flow. A flow characterized by agitated and irregular, random-velocity fluctuations.

Turbulence. A type of flow in which any particle may move in any direction with respect to any other particle and not in a smooth or fixed path. Turbulent water is agitated by cross current and eddies. Turbulent velocity is that velocity above which turbulent flow will always exist and below which the flow may be either turbulent or laminar.

Two-dimensional model (2-D). A mathematical model defined along two spatial coordinates where the water quality constituents are considered averaged over the third remaining spatial coordinate. Examples of 2-D models include descriptions of the variability of water quality properties along: (a) the length and width of a river that incorporates vertical averaging of depth, or (b) length and depth of a river that incorporates lateral averaging across the width of the waterbody.

Ultimate Biochemical Oxygen Demand (UBOD or BOD_U). Long-term oxygen demand required to completely stabilize organic carbon in wastewater or natural waters.

Uncertainty factors. Factors used in the adjustment of toxicity data to account for unknown variations. Where toxicity is measured on only one test species, other species may exhibit more sensitivity to that effluent. An uncertainty factor would adjust measured toxicity upward and downward to cover the sensitivity range of other, potentially more or less sensitive species.

Unstratified. Indicates a vertically uniform or well-mixed condition in a waterbody. See also stratified.

Use Attainability Analysis (UAA). A structured scientific assessment of the factors affecting the attainment of the use which may include physical, chemical, and economic factors as described in section 131.10(g). (40 CFR 131.3)

Validation (of a model). Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation.

Verification (of a model). Testing the accuracy and predictive capabilities of the calibrated model on a data set independent of the data set used for calibration.

Virus. Submicroscopic pathogen consisting of a nucleic acid core surrounded by a protein coat. Requires a host in which to replicate (reproduce).

Volatilization. Process by which chemical compounds are vaporized (evaporated) at given temperature and pressure conditions by gas transfer reactions. Volatile compounds have a tendency to partition into the gas phase.

Wasteload allocation (WLA). The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).

Wastewater. Usually refers to effluent from a sewage treatment plant. See also domestic wastewater.

Wastewater treatment. Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water in order to remove, reduce, or neutralize contaminants.

Water quality. The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.

Water quality-based effluent limitations. Effluent limitations applied to dischargers when mere technology-based limitations would cause violations of water quality standards. Usually WQBELs are applied to discharges into small streams.

Water quality-based permit. A permit with an effluent limit more stringent than one based on technology performance. Such limits may be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry or water supply).

Water quality criteria. Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.

Water quality-limited segments. Those water segments which do not or are not expected to meet applicable water quality standards even after the application of technology-based effluent limitations required by sections 301(b) and 306 of the Clean Water Act (40 CFR 130.29(j)). Technology-based controls include, but are not limited to, best practicable control technology currently available (BPT) and secondary treatment.

Water quality standard. Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an anti-degradation statement.

Watershed-based trading. Watershed-based trading is an efficient, market-driven approach that encourages innovation in meeting water quality goals, but remains committed to enforcement and compliance responsibilities under the Clean Water Act. It involves trading arrangements among point source dischargers, nonpoint sources, and indirect dischargers in which the "buyers" purchase pollutant reductions at a lower cost than what they would spend to achieve the reductions themselves. Sellers provide pollutant reductions and may receive compensation. The total pollution reduction, however, must be the same or greater than what would be achieved if no trade occurred.

Watershed protection approach (WPA). The USEPA's comprehensive approach to managing water resource areas, such as river basins, watersheds, and aquifers. WPA has four major features—targeting priority problems, stakeholder involvement, integrated solutions, and measuring success.

Watershed-scale approach. A consideration of the entire watershed, including the land mass that drains into the aquatic ecosystem.

Watershed. A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Wetland. An area that is saturated by surface water or ground water with vegetation adapted for life under those soil conditions, as in swamps, bogs, fens, marshes, and estuaries.